

Screwworm Eradication Data System (SEDS)

Evaluation of SEDS: A Report From the USDA
Members of the Joint Evaluation Team.

EVALUATION OF SEDS: A REPORT FROM THE
USDA MEMBERS OF THE JOINT EVALUATION TEAM

April 1976

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION.	1
SEDS.	1
Approach.	4
EXECUTIVE SUMMARY OF MAJOR FINDINGS AND CONCLUSIONS . .	6
Temperature Estimation and Screwworm Population Dynamics.	6
The Crop Moisture Index	8
The SEDS Model.	9
Technology Transfer, Costs and Benefits of SEDS . . .	11
RESULTS OF THE EVALUATION	12
A. Temperature Estimation.	12
B. The Crop Moisture Index	32
C. The SEDS Population Growth Model.	36
The Current SEDS Predictive Model	47
D. Technology Transfer; Costs and Benefits	64
REFERENCE MATERIAL.	78

LIST OF ILLUSTRATIONS

<u>Table</u>	<u>Page</u>
1 Average Percent of Usable Pixels Available for Estimating Mean Air Temperatures.	16
2 Maximum and Minimum Percent of Usable Pixels Available for Estimating Daily Mean Air Temperature	18
3 Descriptive Statistics on Selected DMAT Error Distributions	27
4 Standard Deviations for Temperature Differences in Degrees Centigrade Between Non-Control Ground Truth Stations and DMAT. . . .	28
5 Percentage of SEDS Growth Potentials Greater Than Actual Growth.	40
6 Number of Texas Counties Which Had Combined Growth Potentials Lower Than One.	43
7 Differences in Growth Potential Calculated From DMAT and Hourly Average for Selected Days. .	44
8 Intercorrelation Matrices of SEDS Predictors and Criterion (AGR) Variables by Zone	51
9 Case Requests for Kenedy County, 1975	59
10 Confirmed Screwworm Samples and "Other Samples".	61
11 Total Costs Plus Losses to U.S. and Mexico for U.S. Barrier Program and U.S.-Mexico Screwworm Programs.	68
12 Estimated Costs of USDA Operation of SEDS	73

<u>Figure</u>		<u>Page</u>
1	Distribution of DMAT Errors: April 5-11. . . .	23
2	Distribution of DMAT Errors--Radiometric: March 29-April 4.	24
3	Distributions of DMAT Errors--Night Radiometric: March 29-April 4.	25
4	Average Temperature During Adult Phase Prior to First Oviposition.	37
5	Average Moisture Conditions as Measured by the Palmer Crop Moisture Index During the Pupal Phase	38
6	Relationship Between Mean Air Temperature and Growth Per Generation	42
7	Monthly Screwworm Cases for Texas (1962-1974) .	56
8	Screwworm Case Reports 1975: Kenedy County, Texas	58
9	Cumulative Costs Plus Losses to U.S. and Mexico for U.S. Barrier and U.S.-Mexico Program	67

EVALUATION OF SEDS: A REPORT FROM THE USDA

MEMBERS OF THE JOINT EVALUATION TEAM

INTRODUCTION

SEDS

The Screwworm Eradication Data System (SEDS) was developed by the Health Applications Group at the Johnson Space Center of NASA for the purpose of assisting the Mexican-American Screwworm Commission in its screwworm eradication effort in Mexico. It is a sophisticated weather data system designed to produce information relative to the local environment in Mexico that is conducive to the growth of screwworm populations or areas where screwworms are not likely to exist.

The Screwworm Eradication Data System is comprised of eight individual measures which are derived from two basic components. The first basic component is temperature which is measured from either a satellite source or meteorological stations. The second component is moisture which is introduced as a crop moisture index. These two components are subsequently broken down into the following elements:

1. Short term mean air temperature.
2. Short term mean air temperature growth potential.
3. Long term mean air temperature.
4. Long term mean air temperature growth potential.
5. Degree day sum.
6. Degree day sum growth potential.
7. Crop moisture index.
8. Crop moisture index growth potential.

It was felt that through these eight elements a predictive model had been developed.

NASA began in February 1975 to accumulate data--the necessary weather data so that an evaluation of the model could be made. To accomplish this end a Joint Evaluation Team (JET) was established by the United States Department of Agriculture (USDA) and the National Aeronautics and Space Administration (NASA) to evaluate the Screwworm Eradication Data System (SEDS) for possible implementation into the USDA, APHIS Screwworm Program. The authority for the team was based on the exchange of letters dated October 14, 1975, between Doctors Mulhern and Edminister of the USDA and Mathews of NASA after SEDS was declared operational by NASA. The principals of the evaluation team were Dr. S. C. Gartman, (Elected Chairman) Mr. George Bickerton, Dr. James Novy, and Dr. Wendell Snow of USDA and Dr. C. M. Barnes of NASA. Dr. Novy was replaced during the meetings by Dr. Chris Hofman. Dr. DelVar Peterson, and Mr. Kenneth Wissmann, both of USDA, served as technical consultants. The joint evaluation team has met seven times from August through January for periods of two-three days each and was supported by NASA and USDA civil servants as well and NASA contractors who provided technical input for discussions.

The JET responsibilities and areas of investigation were accepted as proposed in the letter from Dr. Mulhern, dated October 14, 1975, and sent to Mr. Charles Mathews of NASA. These are presented below:

1. Evaluate whether the SEDS provides reliable predictive information related to screwworm habitat.
2. Determine SEDS output product requirements.
3. Evaluate the utility of output products in field operations.
4. Provide for ground truth and historic and current insect case data to support the evaluation effort and for further model improvements.
5. Conduct a cost-benefit analysis of the SEDS utilization.
6. Define the steps leading to technology transfer, assuming favorable evaluation of the SEDS.
7. Determine the value of other field information to the screwworm eradication effort and provide the necessary information for input into SEDS.

In addition to the objectives set forth in the letter to Mr. Mathews one additional condition and a restraint was agreed to and placed on SEDS. This condition was that SEDS would provide a numerical estimate of the screwworm growth potential. The restraint was that the present model would not be modified except for elevation and emissivity corrections, substitution of the Delta T field and the routine changes in the temperature conversion or DMAT coefficients.

Approach

Although SEDS was developed as a set of weather potential functions it was presented as a predictive tool which would provide numerical estimates of screwworm growth potential (CGP) for specific geographical areas which included 90 southern Texas counties. It was felt that this estimate should be reliable to be of value to the eradication program.

In addition to the combined growth potential (CGP), the following information was requested and supplied by NASA. These were:

1. Short term mean air temperature (STMAT).
2. Short term mean air temperature growth potential (STP).
3. Long term mean air temperature (LTMAT).
4. Long term mean air temperature growth potential (LTP).
5. Crop moisture index (CMI).
6. Crop moisture index growth potential (CMP).
7. Degree day sum (MPT).
8. Degree day sum growth potential (MPTP).

SEDS was proposed to have the capability of expressing these eight products in both photographic and numeric form and was evaluated in both forms. The evaluation of the results are found in later sections of this report. However, they were carried out using the following format. The evaluation of the temperature elements was accomplished by comparing the SEDS outputs of each element with those obtained from meteorological stations referred to as ground truth

data. The validity of the crop moisture index was not evaluated, but various authorities on soil moisture were consulted. The growth potential elements were analyzed using a statistical approach and the final combined growth potential composite was analyzed by comparing predicted values from SEDS with what occurred in the field. The time intervals proposed were a spring evaluation period from March through June 1975; a fall evaluation period from October through December 1975; and a "real time" evaluation period during the spring of 1976.

It was agreed that JET would make use of all reference materials and reports of studies made by NASA staff or its SEDS contractors. Furthermore, JET would review and analyze all material available for potential impact on the SEDS evaluation.

EXECUTIVE SUMMARY OF MAJOR FINDINGS AND CONCLUSIONS

The scope of this study of the Screwworm Eradication Data System (SEDS) was comprehensive. Accordingly, the evaluation methodology was formulated in such a manner that all major aspects of the system would be addressed. A detailed discussion of each finding is presented in the section of this report entitled "Results of the Evaluation."

Temperature Estimation and Screwworm Population Dynamics

The capability of SEDS to estimate daily mean air temperature for selected ground locations is a significant part of the system under evaluation. The adjustment of radiometric values for distortions introduced in the measurement process is facilitated by accurate charts of ground elevations. Presently, elevation maps for U.S. areas are available. It is important to note that the availability of high quality elevation charts for areas in Mexico is minimal and, in some areas, nonexistent.

The registration of satellite images to reference points on the ground seems to be within the capability of current technology. Evaluation data suggest that most points used by SEDS are within ± 12 to 16 miles of the true ground reference. With regard to resolution of the satellite sensors, it has been reported that areas which are less than 12 to 14 miles square are not discernable on SEDS products. This raises doubts that certain canyons or other relatively small areas which have adequate ecology for screwworms will be identified as such by SEDS.

Currently, a NOAA satellite makes two passes per day over ground locations of interest and inputs data to SEDS. Only data which is not contaminated by cloud cover or minor mechanical system problems is usable for temperature estimation. For the spring 1975 evaluation period, it is estimated that satellite data for Texas was available, on the average, 50 percent of the time. There was, of course, some variability in these data. The lowest and highest observed averages were 31 and 83 percent. Interpretation of the 50 percent average figure should be made in light of the fact that individual ground points may yield no data for days at a time. The majority of consecutive days of missing data were in the range of 1 to 3 days for 16 selected Texas cities. A few exceptionally long periods of 18 to 20 days were observed.

When data is available, it is estimated that the SEDS daily mean air temperature is generally within ± 4 degrees centigrade of ground truth. However, it is quite possible for DMAT errors for individual locations to be 15 degrees from actual air temperature. The effects of any temperature errors are subsequently passed on to the three other temperature products which SEDS derives from DMAT.

These deficiencies significantly impact the decision making capability for which SEDS was developed.

While the above provides an expectation of the level of precision in average air temperature values, the relevance of this estimate merits, at least, further research. From an entomological perspective, air temperatures 5 feet above the ground are less critical to screwworm pupae than actual soil temperature.

Screwworm pupae respond to soil conditions and only indirectly to changes in climate above the ground. Factors such as soil moisture, and vegetative cover may indirectly influence the adult fly. With respect to the temperature effects on adult screwworm activity, it is conceivable that hourly temperature inputs might provide valuable information to the system. Findings to date indicate that available remote sensing technology does not currently provide soil temperature readings.

The Crop Moisture Index

The sole non-temperature variable used in SEDS is a composite index of evapotranspiration anomaly and soil wetness developed by Palmer (CMI). CMI is calculated for several large geographic areas and was devised to yield only a coarse measure of moisture to be generalized across the area. If SEDS products are to be used in small areas, local climate and soil variations would not be reflected in the general CMI index for the area. The manner by which CMI is presently incorporated in the SEDS predictive model does not allow soil moisture to be a limiting factor. That is, when soil moisture conditions are extreme and not supportive of screwworm populations, population growth potentials based on CMI will be estimated by SEDS to be greater than one (i.e., population growth is predicted).

The fact that CMI values are developed with regard to moisture levels typical for a climatological region introduces a problem which is, at least, controversial. CMI is a numerical value which is relative

to a region. A value of 1.6 indicates a discrepancy from the "expected" moisture in that region. Since regions do not normally have identical expected moisture levels, 1.6 CMI changes meaning from one region to another. However, the SEDS model treats these relative values as if they could be interpreted directly, across any climatological region.

The epidemiological literature does not show any direct causal relationship between moisture levels and screwworm prevalence. In fact, recent research indicates that soil moisture, within moderate tolerances, has little bearing on survival of the pupae in the soil.

Moreover, it is simplistic to assume that weather factors alone (as indexed by temperature and CMI) affect population trends in screwworm populations. Several other factors should be investigated to assess their impact on the dynamics of this insect.

The SEDS Model

The SEDS products discussed above are combined to create one overall index of screwworm growth potential. Each of the temperature products and CMI, as well as the combined index, can be obtained from SEDS for geographic areas of interest. The evaluation committee has concluded that the development of mathematical relationships for the SEDS growth potentials was done, in part, arbitrarily and in the absence of clear scientific documentation. Materials produced in the early phases of the SEDS project attest to the tentative nature of these relationships as first approximations. Necessary, scientific support (in the form of factual information from well designed research studies) is not yet available.

The SEDS model is one which makes use of statistical relationships found in the SEDS developmental studies. Data on the temperature and moisture variables are weighted according to a mathematical formula. It is clear that the high degree of overlap among the three temperature variables and the relatively low relationship of each variable to actual population growth rate are just two factors which preclude an acceptable level of predictability for this model.

An additional consideration is that confirmed case reports of screwworm are not considered to be quantitative values. Case reporting is one indicator of the presence of screwworms and the very indicator on which the SEDS model was constructed.

Setting aside a statistical argument, the model may be judged as incomplete from entomological and epidemiological points of view.

SEDS is "timed" so that short-term temperature values are keyed to a population of flies which is four-days old when the satellite makes a pass. Considering that there is a required period of time for data processing, the SEDS predictions will arrive in the hands of an epidemiologist too late to be used on that population. This may result in the release of sterile flies in areas where most population mating has already occurred. It has been suggested that variables such as the availability of host populations, food sources, vegetative cover, animal husbandry practices, persistence of wounds, rainfall, wind, relative humidity, soil types, daily temperature extremes and the activities of the USDA eradication program (sterile fly release) represent only a partial list of factors which rival the importance of temperature and relative soil moisture.

In summary, the SEDS model demonstrates a marginal relationship to screwworm population dynamics and considers a complex set of phenomena from the narrow perspective of weather alone.

Technology Transfer, Costs and Benefits of SEDS

Available documentation on SEDS is, as yet, inadequate for full transfer of technology to a new operation. A major concern raised by the committee focused on the absence of appropriate quality control mechanisms to identify when the system generated a product of unacceptable quality. It is difficult with present SEDS data to document a favorable cost-benefit ratio because the programs involved are still in a research and development stage. There is no evidence that the perceived benefits of SEDS will be realized.

Additional comments on the need for modification of the SEDS system were received from NASA contractors. Dr. Alberto Broce, LEC/NASA (15) completed a study titled "Subjective Analysis of SEDS" and concluded "In light of the present study, SEDS does not appear to be operational for field use in its present configuration."

In view of the above, it is the opinion of the committee that this system (SEDS) is not functionally operational for use by Veterinary Services in the Screwworm Program.

RESULTS OF THE EVALUATION

The Screwworm Eradication Data System is a highly structured and complex configuration. Four interrelated aspects of the system were reviewed by the Product Evaluation sub-committee and the Cost/Benefits sub-committee of the JET. The results of this evaluation will be discussed in conjunction with committee interpretation of the impact on the USDA screwworm eradication program. The four general areas are:

- A. Temperature Estimation
- B. The Crop Moisture Index
- C. The SEDS Predictive Model
- D. Technology Transfer; Costs and Benefits
- A. Temperature Estimation.

The estimation from satellite data of the daily mean air temperature is the nucleus around which the SEDS system is constructed. With the exception of the crop moisture index, all SEDS products are derived from this single measurement of air temperature for each ground location of interest. Consequently, factors affecting the reliability and validity of the estimated values must be identified and appraised in terms of difficulties to be encountered under normal system operations.

Currently, a NOAA satellite transmits radiometric temperature values in analog form over land areas of interest to the screwworm eradication effort. The conversion of these radiometric values from analog to digital form is the initial step in obtaining temperature values. The conversion process requires approximately 8 hours of data processing time for each day (2 passes) of satellite data.

The resulting temperature values are adjusted for two factors which depend on earth surface characteristics. Corrections for distortions due to local emissivity and elevation are currently operable in SEDS but the adjustments are described as relatively coarse. Some significant improvements can be effected by the addition of more highly detailed elevation charts and modification of the present SEDS software (1). Phinney (2) has commented that the level of detail in elevation maps of Mexico is less than the Texas maps currently used by SEDS. Refinement of the elevation values would improve the ability of SEDS to estimate temperatures in Mexico.

Whenever successive passes over a ground location must be integrated, there is need for a mechanism to register data to the same ground point. Phinney (3) has observed that "the quality of the registration of the radiometric data to the SEDS reference image is extremely important. Without accurate registration, no meaningful comparison can be made between surface mean air temperature and the satellite observed radiometric temperature." The registration of SEDS data seems to be within the capability of current technology. S. Boatright (4), in her report of October 16, 1975, indicated that a "best estimate" of the standard deviation for the horizontal (pixel) elements is 3.5 and for the vertical (scan) is 2.8 elements (each element is approximately 885 meters square). The "best estimate" was determined at the center of the image. The standard deviation increases from the center of the picture to the edges.

Expressing this variation in terms of land area and screwworm habitat, it means that 67% (+1 standard deviation) of the pixels are within +3100 meters ($3.5 \text{ elements} \times 885 \text{ meters/element} = 3100 \text{ meters}$ or 1.92 miles) of the correct ground reference point and that 67% of the scans are within 2500 meters ($2.8 \text{ elements} \times 885 \text{ meters/element} = 2500 \text{ meters}$ or 1.54 miles) of the correct ground reference point. Additionally, it can be assumed that 95% (+2 standard deviations) of the pixels and scans fall within +3 to 4 miles of the true ground point. SEDS does not use each pixel of the original NOAA image. Every fourth pixel is sampled and becomes a "super-pixel" for use in SEDS. Consequently, it would be expected that 95% of the registered points would fall within +12 to 16 miles of the correct ground reference point.

With regard to the resolving power of SEDS, it has been reported that areas which are less than 12 to 14 miles square are not discernable on the SEDS products. Therefore, canyons or other small areas which have adequate moisture, vegetation, and a host population and a high potential for screwworm growth may pass undetected by SEDS.

In a special study of the Reyes Canyon area (Mexico), Arp (5) used satellite temperature values to produce a detailed map of the canyon. This illustrates the potential of the system, but it should be emphasized that Arp's study was somewhat atypical. He used the individual pixels (i.e., the smallest resolution available) and not the "super-pixel" normally used by SEDS. Additionally, the

Experimental results are given in Table I and are summarized

below. It seems that the (1) standard deviation of the plasma

and which (2) is about 10% of the standard deviation of the plasma

and (3) is about 10% of the standard deviation of the plasma

and (4) is about 10% of the standard deviation of the plasma

and (5) is about 10% of the standard deviation of the plasma

and (6) is about 10% of the standard deviation of the plasma

and (7) is about 10% of the standard deviation of the plasma

and (8) is about 10% of the standard deviation of the plasma

and (9) is about 10% of the standard deviation of the plasma

and (10) is about 10% of the standard deviation of the plasma

and (11) is about 10% of the standard deviation of the plasma

and

Table I. The results of the experiments are given in Table I.

and (12) is about 10% of the standard deviation of the plasma

and (13) is about 10% of the standard deviation of the plasma

and (14) is about 10% of the standard deviation of the plasma

and (15) is about 10% of the standard deviation of the plasma

and (16) is about 10% of the standard deviation of the plasma

and (17) is about 10% of the standard deviation of the plasma

and (18) is about 10% of the standard deviation of the plasma

and (19) is about 10% of the standard deviation of the plasma

and (20) is about 10% of the standard deviation of the plasma

and (21) is about 10% of the standard deviation of the plasma

detailed map could not be obtained from every satellite pass. Out of the five passes of the Reyes Canyon, only one provided sufficient detail to support the Arp study. The other passes were contaminated due to several possible causes.

Contamination of the satellite data is often due to pervasive cloud cover in the area, or minor mechanical problems such as recorder shut-off or breaks in data transmission. Uncontaminated data is known as available satellite data. In a study of the spring 1975 SEDS data, the Product Evaluation sub-committee estimates that cloud-free data from the twice-daily satellite pass in Texas was available, on the average, 50 percent of the time. This figure varied for different sections of the country; the highest average for available data was 83 percent. The lowest was 31 percent.

Table 1 shows the availability of satellite data in 14 counties during part of April, all of May and June (1975). These data were taken from the N-Good figure on the Aeroneutronic-Ford summary of SEDS products during the evaluation period. The figures represent the percent of the "14 day average" for all pixels in the county. The counties were selected as representative of those having low, medium and high available satellite data. Most of the areas had significant increases in usable satellite data from April to June. However, four areas--Reyes, Colima, Fortin, and Cameron--decreased during this time period. (The variation is an expected seasonal variation and changes for different sections of the country.)

TABLE 1

AVERAGE PERCENT OF USABLE PIXELS AVAILABLE FOR
ESTIMATING DAILY MEAN AIR TEMPERATURES BY TIME PERIOD

<u>County</u>	<u>April 20-30</u>	<u>May 1-31</u>	<u>June 1-27</u>
Brazos	18	26	45
Colorado	17	26	46
Gonzales	15	34	53
Matagorda	20	27	45
Washington	20	27	42
Cameron	56	49	42
Gillespie	43	46	54
Hidalgo	58	56	57
Hudspeth	54	70	71
Ward	53	77	80
Jeff Davis	71	84	87
Forten	71	66	39
Colima	86	89	62
Rayones	78	66	68
Time Period Average	47.14	53.07	56.50

Table 2 shows the range of percentages for available satellite temperature. There is considerable variation from day to day for a given county as indicated in the magnitude of the range. For example, during the month of May, Brazos County had a day in which 47 percent of the satellite pixels provided good radiometric information. It also had at least one day in which only 3 percent of the pixels provided usable data. These are the extreme values for Brazos County, with the average available satellite data for May being 26 percent (Table 1).

On May 2, Colima had a high of 109 percent satellite information. This artifact was caused when the computer would not read three tapes. The JET was assured that this difficulty only affected the mechanism for tabulating usable pixels and did not affect the temperature values.

TABLE 2

MAXIMUM AND MINIMUM PERCENT OF USABLE PIXELS
AVAILABLE FOR ESTIMATING DAILY MEAN AIR TEMPERATURES BY TIME PERIOD

<u>County</u>	<u>April 20-30</u> <u>High-Low</u>	<u>May 1-31</u> <u>High-Low</u>	<u>June 1-27</u> <u>High-Low</u>
Brazos	23-16	47-3	63-22
Colorado	19-13	45-8	60-25
Gonzales	21-11	55-14	65-37
Matagorda	24-16	51-7	54-27
Washington	24-17	42-12	58-18
Cameron	65-43	67-33	60-27
Gillespie	46-40	62-35	76-36
Hidalgo	72-43	70-40	73-40
Hudspeth	74-42	80-61	89-44
Ward	77-43	89-69	96-53
Jeff Davis	87-61	99-73	101-58
Forten	79-64	97-36	46-26
Colima	96-79	109-65	71-44
Rayones	98-66	100-73	79-41

These difficulties indicate that the system is not fully operational. The error discussed above was first noted on the May 2 printout which means that all the percent satellite data figures from May 2 on, could be as much as 9 percent high.

Given the fact that satellite data is available only 50 percent of the time, a logical question is, "What is the length of the sequence of missing days?". With this in mind, a detailed investigation was done by the Product Evaluation subcommittee on satellite information over the spring test period for 16 Texas cities--Abilene, Waco, Midland, Beaumont, San Angelo, Houston, Austin, El Paso, McAllen, Brownsville, San Antonio, Marfa, Victoria, Del Rio, Cotulla, and Corpus Christi.

The night passes for Beaumont, Waco and Houston had several runs of 18 to 20 consecutive days of missing data. These three cities were more of an exception than the rule. The average run of missing data for the 16 cities was 1.6 days (the night passes for Beaumont, Waco and Houston were excluded from this average). A 9-day interval without satellite data was the maximum period other than those noted above. The majority of the runs were from 1 to 3 days.

When satellite data is available, SEDS estimates the daily mean air temperature (DMAT) for each location of interest. The details associated with estimating DMAT are described in the system documentation available at NASA. Basically, SEDS uses linear regression equations to transform the radiometric satellite data into DMAT. Four separate

equations are used to estimate DMAT depending on the availability of satellite data--i.e. (1) both day and night radiometric data usable; (2) only day radiometric data usable; (3) only night radiometric data usable; and (4) neither day nor night radiometric data usable. Coefficients for the first three equations are referred to as the DMAT coefficients and are determined and adjusted from monitoring the residual DMAT errors.

The DMAT coefficients used during the spring evaluation were derived using temperature values from U.S. and Mexico border stations. There were two different sets of DMAT coefficients used and comments were made (2) that there should have been three sets. The first set of coefficients was developed on March 15-29 data and used until June 5. The second set of coefficients were developed on the May 10-23 data but put into effect on June 5. The time lag between developing the coefficients and implementing them was due to the accelerated processing of the spring data.

With reference to the change in the coefficients during the spring processing, Phinney (6) states that "in the example from 15-29 March 1975, the Bias error for Case 3 (night radiometric data only) was $+0.52^{\circ}\text{C}$ and the rms error was 2.41°C . By 10-23 May 1975, the Bias error had changed to 1.43°C and the rms error to 3.63°C . At that time the DMAT coefficients were recalculated. For the same case, the new Bias error was 0.0°C with a rms error of 2.16°C . Thus, providing the base-line figures for the next evaluation."

In order to get the best temperature estimates it may be necessary to have separate DMAT coefficients for different areas. Phinney (6) alludes to this when he states that "the DMAT estimates for regions well away from the U.S. Mexico border area should be handled with care. The higher elevations experienced in some parts of Mexico are outside the range of data over which the DMAT coefficients were calculated." This problem of extrapolation from the data on which the SEDS model was built may very well lead to greater errors in temperature estimation in Mexico. In order to achieve more precise temperature estimation in Mexico, further research is needed to extend the range of temperature values that the SEDS model may handle with some validity.

The DMAT coefficients are extremely important in estimating the DMAT values. There are three points to be emphasized; first, the DMAT coefficients need to be exact. This requires constant monitoring of the daily temperature values by a trained professional. Secondly, the DMAT coefficients are very sensitive and can be used without change for about one month; and thirdly, the SEDS system needs to be improved to automatically change the coefficients.

Inasmuch as the SEDS model relies on linear combinations of DMAT, the predictive validity of the model depends on the accuracy of the DMAT estimates. In order to evaluate the magnitude and type of error to be expected when estimating DMAT, SEDS project staff have carefully documented errors on a weekly basis for the full spring

evaluation period. The definition of error always involves a true value against which an estimated or predicted value is compared. In the case of SEDS, true values of temperature were collected for 95 selected meteorological stations in southern Texas. For those same locations, DMAT was estimated using equations dependent on the available radiometric data for each day. The arithmetic difference between the true and estimated temperatures has been defined as error; the weekly average of these errors has been termed "bias error" in the SEDS documentation. Variability in the size of expected errors is also quite important to potential users of SEDS. The statistical measure of variability commonly referred to as the standard deviation has been calculated by the SEDS staff. This can be interpreted as a measure of spread in the error distribution (i.e., to what extent errors deviate from their central or average value.)

These two summary statistics on the error distributions are helpful to the extent that they communicate the accuracy of individual predictions to users of the system. Unfortunately, it is easy to misinterpret their meaning. In order to clarify the meaning of some typical DMAT error distributions, data were graphed for the weeks of March 29-April 4, and April 5-April 11, 1975, and is shown in Figure 1, 2, and 3. Reference to Table 3 reveals that the average observed difference between DMAT and ground temperature (bias error) is relatively small (1.5°C or less). The standard deviations for these distribution also seem "small." However, a better representation

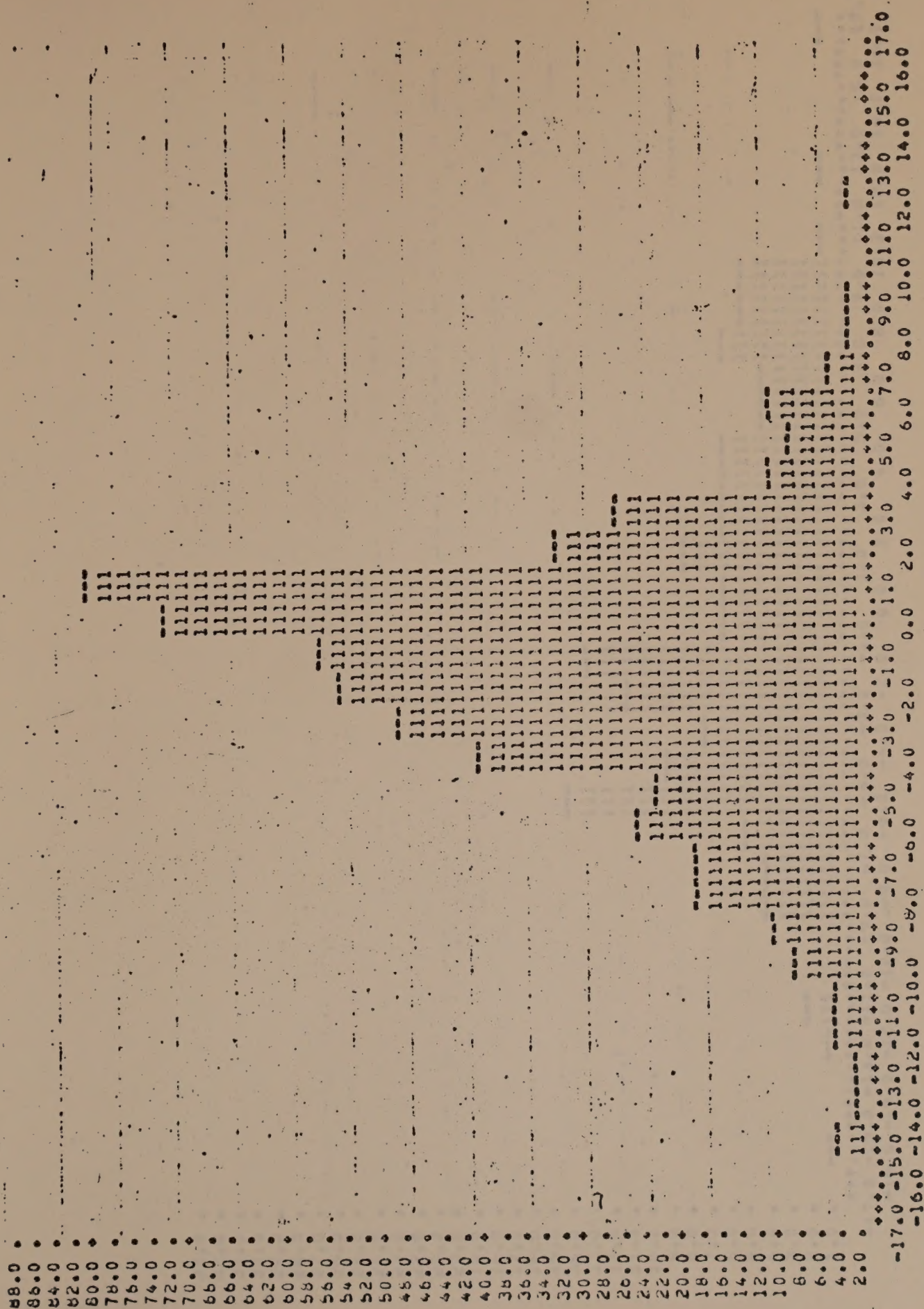


Figure 1
Distribution of DMAT Errors: April 4-11

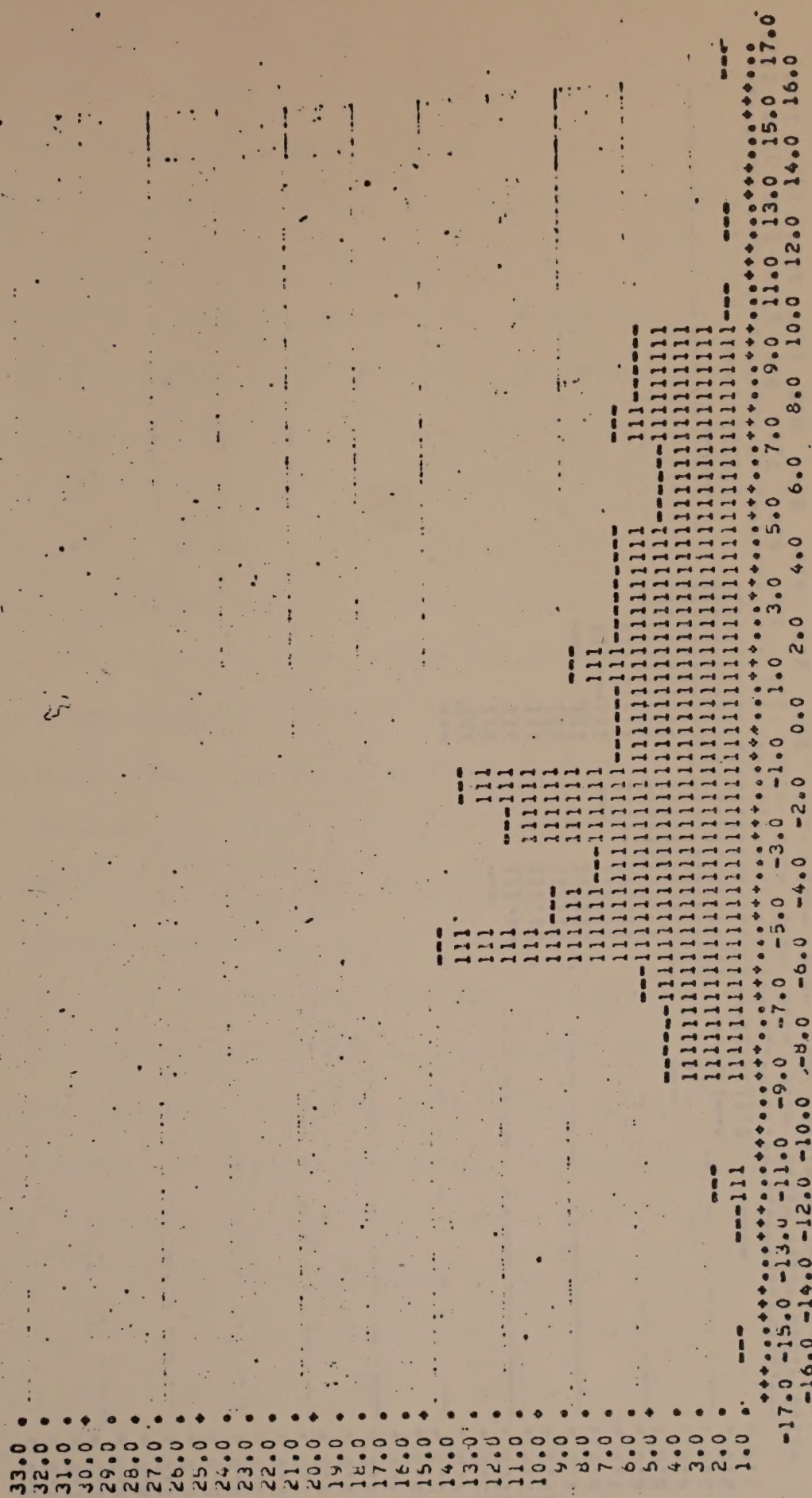


Figure 2
Distribution of DMAT Errors - Day Radiometric: March 29-April 4



Figure 3
Distribution of DMAT Errors - Night Radiometric: March 29-April 4

of the spread of errors is given in the last two columns of Table

3. These data suggest that it is quite possible for individual DMAT errors to be 12 to 15 degrees from ground truth in either direction. In fact, it is not unreasonable to estimate that fully 25 percent of DMAT's will either overestimate or underestimate ground temperatures by more than 5°C. The effects of such errors are subsequently passed throughout the SEDS system since the distorted DMAT's contribute to growth potentials for STMAT, LTMAT, and MPT.

In order to provide additional data on the estimation errors across the entire spring period, the mean air temperatures for surface meteorological stations for the United States and Mexico were reviewed. Some of these met-stations were used by SEDS as "control" ground truth stations to verify DMAT estimates. Data from the remaining non-control met-stations are reported in Table 4. The reason for choosing these stations was that the estimated DMAT and the station temperature were independent estimates of the same temperature.

Table 4 contains the standard deviations for the difference between the noncontrol stations and DMAT estimates. The values are taken from Phinney (7). On the average, the U.S. non-control ground truth stations had an overall standard deviation of 3.1 degrees. From a practical point this means that 95% of the stations are within $\pm 6^{\circ}$ C from the station temperature. Dr. Elwin Taylor (8) indicated that "with the current technology, 95% of the estimated temperatures should be in the range of $\pm 4^{\circ}$ C." This would suggest that temperature estimates from SEDS are 50% more variable than what is possible to obtain in the U.S. Non-control stations in Mexico appear to be somewhat more variable than their U.S. counterparts.

Dates	Station Grouping	N	Bias Error (°C)	Standard Deviation	Range of Errors	Percent Exceeding + 1 Standard Deviation
April 5-11	All non-missing stations	550	-1.25	3.93	-14.7 +12.8	30
March 29- April 4	Day radiometric usable	137	- .198	6.04	-15.5, +16.1*	28
March 29- April 4	Night radiometric usable	94	-1.34	4.79	-13.0, + 9.6**	23

* Actual error of 25° was observed. Interpreted as "bad data" on 1/23/76 by SEDS project team.

** Actual error of 22° was observed. Interpreted as "bad data" on 1/23/76 by SEDS project team.

Table 4

Standard Deviations for Temperature Differences in degrees C.

Between Non-control Ground Truth Stations and Estimated DMAT

Date	U.S.		Mexico	
	s	n	s	n
3/29 to 4/4	5.6	75	4.1	76
4/5-11	3.1	102	3.1	62
4/12-18	3.3	89	3.3	97
4/19-25	3.0	74	3.6	46
4/26-5/2	3.0	74	3.8	42
5/3-9	2.2	63	3.4	50
5/10-16	3.4	44	4.0	67
5/17-23	2.4	28	4.3	85
5/24-30	2.8	60	3.8	94
5/31-6/6	2.0	41	3.8	103
6/7-13	3.0	55	3.4	115
Average	3.1		3.7	

Boatright (1) indicates that modifications to the current SEDS temperature estimation may be made to improve the accuracy. An additional problem reported by Boatright is evidenced by a trend in the temperature residuals. Presently, SEDS routinely underestimates temperatures in the northern regions of the evaluation area but overestimates temperatures in the southern region (i.e., a trend for positive residuals in the north and negative residuals in the south).

It should be clear that part of the difficulty with temperature estimation is directly related to the coefficients used to create DMAT. If the coefficients (weights) used to combine satellite temperature and altitude observations are "good," the average error is expected to be near zero and the standard deviation is quite small. It is also assumed that the appropriate weighting should not change markedly over time or in response to other factors not currently measured. If a loss of accuracy in the estimates is detected by a shift in average error or increase in variability, some immediate action is indicated. A decline in accuracy may reflect a change in data quality, or the need to "update" the coefficients in response to changing meteorological conditions. Both conditions are troublesome and may be difficult to properly differentiate. The latter condition apparently occurred during the spring evaluation period and prompted a recalculation of the DMAT equations.

From the perspective of a system user, such revisions necessitate careful documentation which, to date, has not been provided by the SEDS project staff. Our preliminary appraisal of this problem suggests that the minimal required information consists of:

1. What are the criteria which determine that a change is necessary?

These should be expressed in terms of limits on average error and variability of the error distribution. Additionally, is it necessary to modify the DMAT coefficients when the system is used over areas not previously reflected in the derivation of the coefficients? That is, when SEDS is used in Mexico, is there sufficient evidence supporting the accuracy of current DMAT coefficients or is a new study necessary?

2. If an update is indicated, what data must be used to insure adequate representation of the variety of meteorological conditions under which DMAT will be estimated. For example, if data is available for a full calendar year, should sampling be carried out within seasons or across the entire year? What are the characteristics of existing SEDS history files (what geographic areas and time periods covered; how often are they updated.)

3. What specific software changes are necessary to implement new DMAT coefficients?

The above mentioned difficulties involve the estimation of only one SEDS component, DMAT. The SEDS model builds on this component and attempts to identify ground locations with a high potential for screwworm population growth.

From an epidemiological point of view, there is little doubt that temperature extremes control insect populations, including screwworms. The impact of temperature upon screwworm populations, however, should be used cautiously since all the effects are not known, nor is it known

which stage in their life cycle is affected the greatest. The studies of Flitters, et. al, (9), demonstrated that under laboratory conditions a direct correlation could be assigned to the development of pupae and temperature. This information was used in the construction of the SEDS model as a component for the screwworm growth potential. However, these were laboratory tests and do not reflect natural conditions. Factors such as soil type, soil moisture, vegetative cover, and daily temperature fluctuations all would be expected to affect the rate of pupal development. Furthermore, the pupae are responding to soil temperatures, not temperatures read at 5 feet above the soil surface.

It is alarming that the SEDS model has limited provision for temperature effects on adult screwworm activity. Biological factors such as temperatures conducive for adult movement would be relevant to the dynamics of screwworm populations, including infestation rates. It is conceivable that for the model to be predictive, temperature input may have to be as an hourly input for adult activities and daily averages for pupal development.

The point is that temperature is a major component of screwworm population dynamics; however, a daily average does not give the precision which is needed nor are the secondary effects of temperature sufficiently defined for or by the model.

B. The Crop Moisture Index.

The Crop Moisture Index (CMI) is used in the SEDS model as an independent variable to represent soil moisture. Rahn and Barger (10) indicated that CMI appears to be a useful guide for estimating screwworm activity, with periods of near or above normal CMI suggesting increased screwworm infestations in the weeks ahead. They caution, however, that these responses were strongly modified by other factors, such as high temperature and the ongoing eradication program.

There are a number of concerns and possible problems with the present use of the CMI term in the SEDS model. First, Palmer (11) indicates that CMI maps present a "generalized" picture where local variations caused by the occurrence or absence of heavy rain or by soil deficiencies are not shown. With SEDS interest and intent being to identify the screwworm potential in the small, localized areas, it appears that CMI is too coarse a tool to provide the needed information for screwworm prediction.

Secondly, CMI is a combination of an evapotranspiration (ET) anomaly index and a wetness index. The general pattern of CMI is that it is at or near zero at the beginning of the growing season, and remains near zero as long as the crop moisture supply and weather are near normal. The index returns to near zero at the end of the growing season. It is quite normal for the available soil water to decrease as the crop matures. Field crops can develop under such a system but screwworms require a specific amount of water for development.

Thus, CMI indicates the moisture conditions necessary to produce the "local" crop and does not indicate the moisture requirement needed for a screwworm pupal development.

Thirdly, CMI is based upon a measure of the weekly "abnormal" ET deficits for a climatological division. This "abnormal" ET deficit is a computed value. It is an estimate of the amount by which the actual weekly ET falls short of the expected weekly ET. Palmer's (11) reason for using the "abnormal" ET as an estimate of maximum moisture needed by crops is because subhumid and semiarid regions have ET deficits much of the time during the summer. A possible difficulty with using CMI stems from the fact that it is a measure of ground moisture which is relative to a particular region. Consequently, a CMI value of zero in one region does not indicate the same amount of ground moisture as does zero in a different region. When used in the SEDS predictive model, however, CMI values which are numerically equal are regarded erroneously as representing the same quantity of ground moisture.

Fourthly, in SEDS, CMI is transformed to a crop moisture potential (CMP). The range of this growth potential is from a low of 1.2 to a high of 3.6. As a result of this transformation, it is impossible for the soil water estimator to become a limiting factor. In reality, however, soil moisture may often be the limiting factor. The transformation also shortens the range of the CMP value which will diminish its correlation with the growth product. A more useful value to use would be the untransformed CMI value.

The implicit reasoning for incorporating CMI in the SEDS model was a weak correlation between moisture levels and screwworm prevalence. There is no independent epidemiological evidence which indicates that this may be a causal relationship. Biologically, this suggests that moisture, per se, is not directly interacting in the population dynamics of screwworms. It should be suggested that there may be other factors which are more directly related to screwworm population dynamics. Available food sources, abundance of cover, or persistence of wounds are a few such factors which are indirectly related to moisture.

It has been assumed in the derivation of the SEDS model that moisture exerts its primary influence on the pupal state. There is no corroborative evidence to support this assumption. In fact there is some fragmentary evidence that soil moisture (12), within moderate tolerances, has little bearing on survival of pupae in the soil. Furthermore, additional tests recently completed (13) have demonstrated that moisture in the form of standing water has little effect on the longevity of adult flies, and suggest that adult flies derive the necessary water from alternate sources.

There is no doubt that moisture exerts an effect on screwworm populations; however, the effects are probably not direct and could be incorporated more appropriately through biological factors other than the Crop Moisture Index.

However, it is simplistic to assume that weather alone (as measured by temperature and CMI) affects population trends in screwworm populations.

In fact, Rahn and Barger (10) showed that while weather did marginally influence screwworm populations, several other factors were at work.

These factors might well include moisture in the following terms:

rainfall (apart from CMI): watersheds including riverbasins, creeks and arroyos; water tanks, vegetative types and effects of rainfall on vegetation. Additional factors which merit consideration are the effects of wind and relative humidity, since ranchers and researchers both have commented that these impact adult fly activity. All these factors should be investigated under a research mode to assess their effects on screwworm populations.

C. The SEDS Population Growth Model.

Four growth potentials or growth per generation functions are developed in SEDS. These assume that the number of screwworm cases occurring in a given week represent a given parent population. The growth per generation was defined as the ratio of the number of cases during a given week to the number of cases reported during the week in which the parent generation occurred (14).

Figures 4 and 5 (14) show the effect of temperature during the adult phase and the effect of moisture conditions during the pupal phase. The curves which represent "envelopes of potential growth" were drawn arbitrarily in the early phases of SEDS development with the intent to revise them in future analyses. To date, scientific facts from well designed research studies are not available to demonstrate these relationships. The growth potential function for short term and long term temperatures are determined from the same arbitrary temperature curve.

The amount of variation found in growth potential relationship is considerable. For example, at an average temperature of 27.5°C , the growth per generation can range from .25 to 5.0. The envelope curve was drawn so that 95 percent of the growth points would always occur below the envelope. The present use of this function incorporates so much variability that its estimated values are meaningless. The same problems exist for the CMI and MPT curves since they were constructed in a similar, arbitrary manner.

FIGURE 4
AVERAGE TEMPERATURE DURING ADULT PHASE PRIOR TO FIRST OVIPOSITION
(REDRAWN FROM PHINNEY)

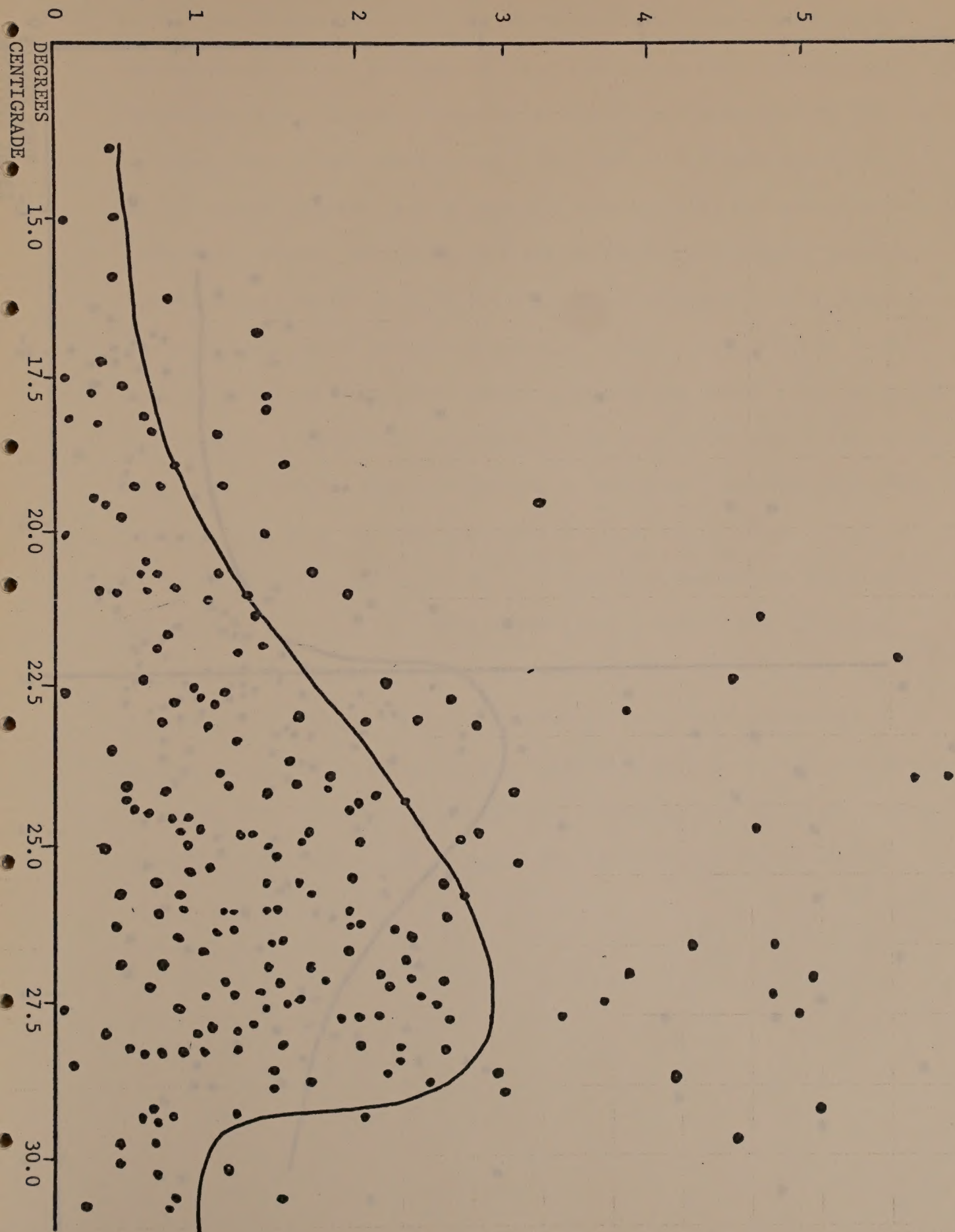
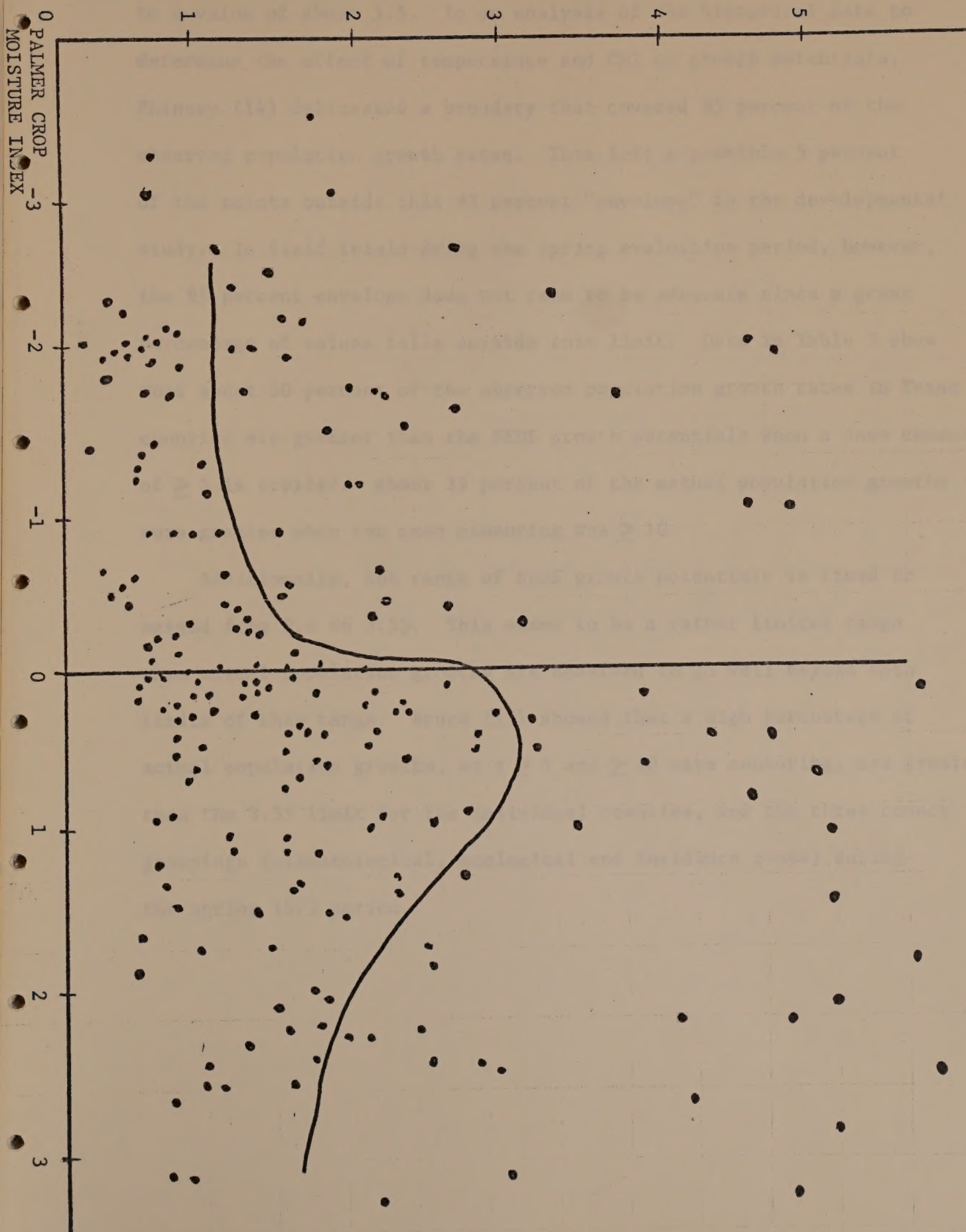


FIGURE 5
AVERAGE MOISTURE CONDITIONS AS MEASURED BY THE PALMER CROP MOISTURE INDEX
DURING THE PUPAL PHASE (REDRAWN FROM PHINNEY)



In SEDS, each of the screwworm growth potentials are maximized to a value of about 3.5. In an analysis of the historical data to determine the effect of temperature and CMI on growth potentials, Phinney (14) delineated a boundary that covered 95 percent of the observed population growth rates. This left a possible 5 percent of the points outside this 95 percent "envelope" in the developmental study. In field trials during the spring evaluation period, however, the 95 percent envelope does not seem to be adequate since a great percentage of values falls outside this limit. Data in Table 5 show that about 50 percent of the observed population growth rates in Texas counties are greater than the SEDS growth potentials when a case censoring of ≥ 5 is applied. About 39 percent of the actual population growths were greater when the case censoring was ≥ 10 .

Additionally, the range of SEDS growth potentials is fixed to extend from 0.6 to 3.55. This seems to be a rather limited range when actual population growths are observed to go well beyond both limits of this range. Broce (15) showed that a high percentage of actual population growths, at a ≥ 5 and ≥ 10 case censoring, are greater than the 3.55 limit for the individual counties, and the three county groupings (climatological, ecological and incidence zones) during the spring 1975 period.

TABLE 5

Percentage of SEDS Data Base Channel Growth Potentials and Combined Growth Potentials are Greater than the Actual Growths, for Counties and Climatological Zones, Sampled 1 Per Week and Case Censorings of ≥ 5 and ≥ 10 , for the Period 3/28 to 6/25/75.

		Sample Points	STP	LTP	CMP	MPT	CGP
Counties	≥ 5	48	41.7	50.0	60.4	45.8	54.2
	≥ 10	26	26.9	42.3	43.8	34.6	42.3
Climatological	≥ 5	37	45.9	48.6	40.5	45.9	40.5
	≥ 10	30	50.0	50.0	46.7	46.7	43.3

The wide range of temperatures for which the growth potential exceeds one is a further indication of problems with the growth potential curves. As indicated in Figure 6, growth potential always exceeds unity for temperatures between 18.8 and 31.6°C. With few exceptions, temperatures in Mexico are consistently within this range. Consequently, SEDS would provide no "new" information about the potential for population growth since temperature conditions are predominantly favorable. In fact, Table 6 indicates that the number of counties within the study area in Texas that had combined growth potentials less than one were very few.

The Product Evaluation sub-committee conducted a study of data from the ARS/USDA Agriculture Experiment Station in Weslaco, Texas for the spring evaluation period. Daily mean air temperatures (as estimated by SEDS) were contrasted with average temperature calculated from hourly readings at Weslaco. Data are reported in Table 7 and indicate that differences in the two averages are relatively small. However, the differences in growth potentials calculated by the two methods show some striking differences. In one case a difference in one degree temperature indicated a difference in GP of .97 where another case with temperature difference of 2.2 degrees had a GP difference of .27. These inconsistencies are disconcerting and imply the need for more refinement and research in the SEDS system.

FIGURE 6

RELATIONSHIP BETWEEN MEAN AIR TEMPERATURE
AND GROWTH PER GENERATION

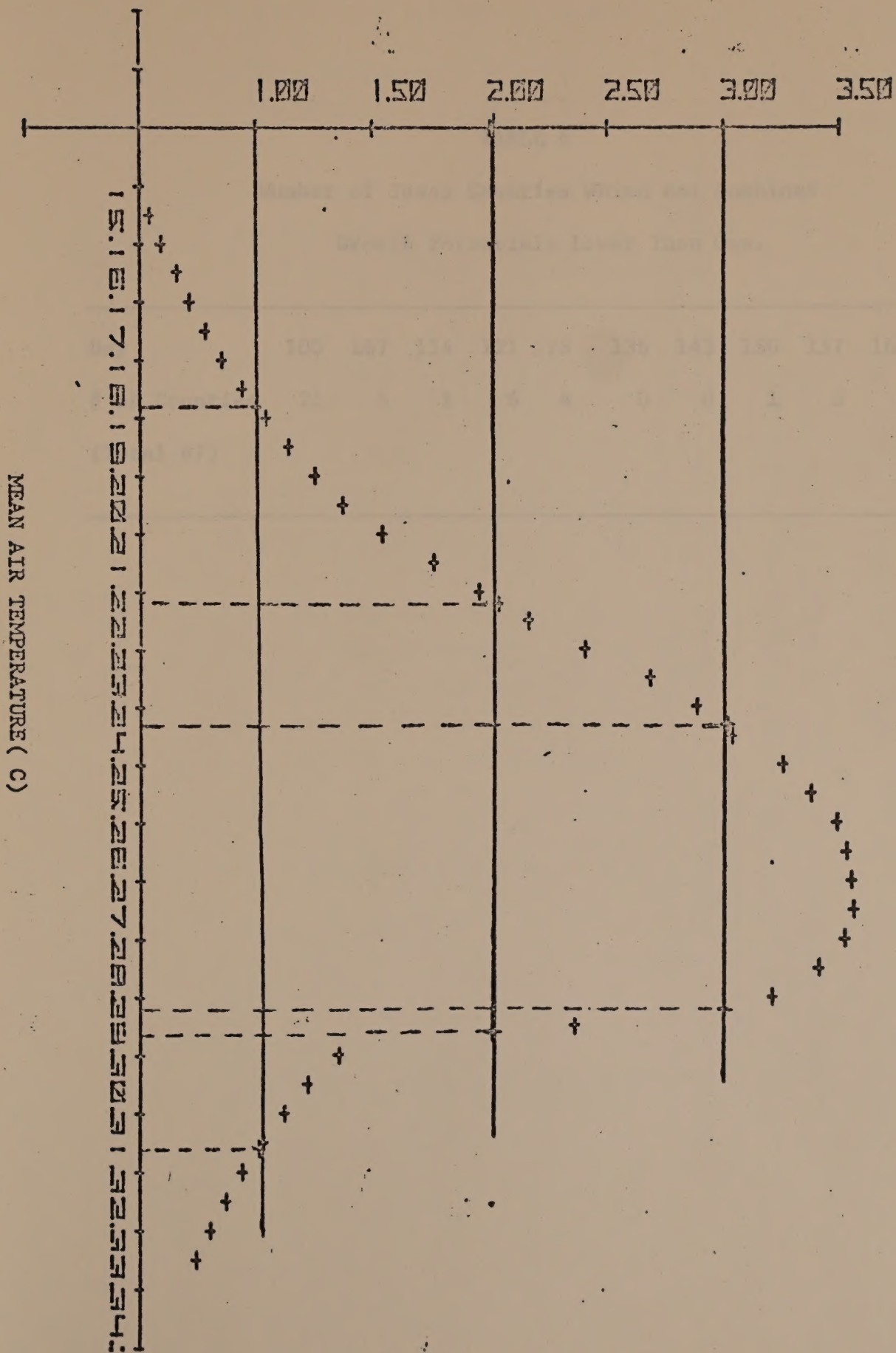


TABLE 6

Number of Texas Counties Which Had Combined
Growth Potentials Lower Than One.

Day	100	107	114	121	128	136	143	150	157	164	171	176
# of Counties	21	5	1	6	4	0	0	1	0	0	0	0
(Total 87)												

Table 7

Differences in Growth Potential Calculated
From DMAT and Hourly Average for Selected Days

SEDS Daily Mean Air Temperature (DMAT)		Daily Mean Calculated From Hourly Temperature		Temperature and GP Differences			
DMAT	Calculated MPT (Days)	DDP Growth Potential	Mean Air Tempera- ture	Calculated MPT (Days)	DDP Growth Potential	Temperature Difference	GP Difference
23.5	10.95	2.71	22.0	12.42	1.90	1.5	.81
19.9	15.29	.68	20.9	13.77	1.10	1.0	.42
19.5	15.99	.60	19.2	16.56	.56	.3	.04
20.5	14.34	.87	20.0	15.12	.70	.5	.17
24.5	10.75	3.30	23.1	11.31	2.53	1.4	.77
22.2	12.20	2.3	21.2	13.38	1.33	1.0	.97
21.9	12.53	1.82	21.4	13.12	1.38	.5	.44
22.5	11.90	2.18	22.4	11.99	2.14	.1	.04
26.7	8.75	3.57	24.5	10.15	3.30	2.2	.27
21.3	13.25	1.35	20.4	14.49	2.3	.9	.85
24.1	10.46	3.04	22.8	11.59	2.35	1.3	.69
24.4	10.23	3.20	22.5	12.45	1.81	1.9	1.39
21.5	13.00	1.50	20.8	13.91	1.05	.7	.45
22.2	12.20	2.02	21.5	13.00	1.50	.7	.57
20.8	13.91	1.05	21.1	13.50	1.25	.3	.20
25.2	9.66	3.55	24.0	10.54	2.03	1.2	1.52

The statistical analysis designed by Broce (15) sought to test the SEDS predictive model by contrasting screwworm population growth rates observed in Texas counties with growth rates as predicted by SEDS for those same counties, during the same time period. The data evaluation period began on March 28, 1975, and extended through June 13, 1975. This is a critical time period since control of the native screwworm population as it attempts to increase in size and geographical range will markedly affect the severity of outbreaks for the remainder of the season.

The mathematical model which formed the basis for a combined screwworm growth potential product was tested against available field data using the statistical technique of multiple linear regression. Historically, the form of the model and the estimates of its parameters were both derived using regression procedures. Evaluation against field data would offer evidence of the predictive validity to be expected under operating conditions. As a byproduct of the regression analysis, the relationships between and among the four variables in the SEDS model could be reexamined.

Since the SEDS model was developed on the basis of a statistical relationship between four predictor variables and population growth rate, such an analysis would determine if these relationships were maintained across time (i.e., generalizable beyond the original data base used in the model development). If so, the model could then be applied in future time periods with some acceptable level of confidence.

An additional question (not addressed by the Broce analysis due to the lack of field data) involves the generalizability of the model to other geographic locations (e.g., Mexico) beyond the areas on which the model was developed.

A measure of native fly population growth rate was constructed from screwworm case reports. Observed growth rate was expressed as the ratio between the number of cases in a given generation and the number of cases in the previous generation. Due to inherent problems in the existing case reporting system, this growth ratio was felt to be unreliable when calculated on a low number of case reports. Consequently, a case censoring of five cases per week was imposed. That is, data for an individual county would be inadmissible for analysis unless that week's case total exceeded five. Actually, a second level of censoring was also imposed setting the level at ten cases; the entire analysis was repeated under this condition.

Since data was collected over a 78-day time period for all counties, it was decided to select data at a rate of once per week for each county and use the resulting data points in the analysis. Additionally, Broce increased the sampling rate to two per week and reran the analysis to identify any differences under the two conditions.

Although data was available pixel by pixel for each county during the evaluation period, various methods of aggregation were employed to reduce the data points to a manageable number. The several ways of combining the raw data were based on defined geographical regions of interest. For example, data was aggregated to the level of a county

to coincide with ground maps of topography and ground cover. Certain combinations of counties were then formed to constitute three "zones" of interest based on ecological, climatological and screwworm incidence considerations.

Thus, when decisions based on the above are taken together, a rather complex set of analytical results is possible. Broce's analysis (15) is therefore an analysis of the predictive accuracy of the SEDS model at four levels of data aggregation, using four sampling strategies each.

Prior to examining the analytic results, a brief review of the SEDS model is presented to facilitate understanding of those results. Full documentation of the model's development and implementation is available in the SEDS literature.

THE CURRENT SEDS PREDICTIVE MODEL

The growth rate of a native population of screwworms is dependent on several factors. Currently, SEDS utilizes climatological factors alone to explain the growth rate phenomena. The SEDS model can be stated as follows:

$$GP = A_0 \text{ STP}^{A1} \text{ LTP}^{A2} \text{ CMP}^{A3} \text{ MPT}^{A4}$$

where

GP = the growth rate of the native fly population

STP = the growth potential based on short term mean air temperature

LTP = the growth potential based on long term mean air temperature

CMP = the growth potential based on the soil moisture of the area

MPT = the growth potential based on an estimate of the screwworm's mean pupation time

A_i for $i = 0, \dots, 4$ are the parameters (coefficients) to be estimated for the model.

This has been called the multiplicative model in the SEDS literature and was chosen from other model forms as a "best" fit to the screwworm data available at that time. The model is intrinsically linear in the sense that the coefficients (the A_i) can be estimated using standard linear regression techniques. When the model was developed, analysis of historical data suggested that a set of coefficients providing a fit to the data could be specified as follows:

$$GP = STP^{.46} \quad LTP^{-.22} \quad CMP^{.36} \quad MPT^{.40}$$

Some of the properties of this model deserve comment. The coefficient, A_0 , has been set equal to one although the rationale behind this is not specified. Additionally, since the maximum value of any growth potential term on the right side is 3.5 and the superscripts sum to 1.00, the maximum value of the combined screwworm growth potential on the left side, GP, is fixed at 3.5. One should note that field data on native populations illustrate growth rates considerably over ten. Therefore, at the outset, model users should be cautious to interpret combined growth potentials a qualitative way as high or low. Rigid adherence to a quantitative interpretation of the numerical values may grossly misrepresent actual growth rates at the upper end of the scale.

According to results presented by Phinney (2) using the historical (normative) data the multiplicative model showed a correlation of $R = .50$ with actual field growth rates. The interpretation of this multiple correlation coefficient exactly parallels that of the regular correlation coefficient: its square indicates the proportion of variability in population growth rate accounted for by its linear regression on the various predictors in the normative sample. It is important to realize that the "proportion of variability accounted for" represented by R^2 (in this case .25) refers only to what is true of the particular sample used in constructing the regression equation. There will almost always be some decrease in the corresponding proportion for subsequent samples. This is why it is necessary to cross-validate the regression equation on an independent sample in order to get a more accurate estimate of the efficiency of actual predictions by the equation.

A criticism often made about linear regression models is that they can be forced to fit almost any set of data thereby giving the appearance of being useful. This statement is not entirely true. The historical data for SEDS illustrates a case where even the "best" regression fit leaves a considerable amount of unexplained variance which can only serve to increase errors when SEDS is used as a predictive tool. The validity of the criticism lies with the fact that estimates of parameters (coefficients) in regression equations are notoriously unstable. Therefore, results from developmental regression models can only be considered as tentative results which gain in validity when they are confirmed by repeated use with new data. The ability

to generalize is increased when the results are substantiated in other locations, and at other time periods. Therefore, field tests within the expected operating environment are the primary source of evidence for appraising a model's usefulness. The spring evaluation period provided a first test of SEDS potential to predict population growth rates in native screwworms.

The ability of a linear combination of variables to predict a criterion depends on the correlations of each predictor variable with that criterion. That is, the use of a variable which is highly correlated with the criterion offers the most promise for accurate predictions. When data on several such "good" predictors are to be combined, the relationships among those predictors assume some importance. From several points of view, the selection of predictor variables which are independent of each other but highly correlated with the criterion is most desirable. In such a case, each predictor variable is adding somewhat unique information (i.e., not contained in the other predictors) to the predictions. When predictors are highly correlated with each other, an overlap of information occurs; one predictor can be used in place of another without a substantial loss of prediction accuracy.

Table 8 illustrates the type of overlap found in the four SEDS predictors during the spring evaluation period. Four intercorrelation matrices are presented since four groupings of the county data were

COUNTRIES					ECOLOGICAL				
	LTP	CMP	MPT	AGR *	LTP	CMP	MPT	AGR	
ST	.84	.56	.86	.25	.87	.63	.88	.29	
LTP		.75	.99	.19		.76	.99	.20	
CMP			.73	.03			.75	.09	
MPT				.21				.23	
CLIMATOLOGICAL									
	LTP	CMP	MPT	AGR	LTP	CMP	MPT	AGR	
ST	.86	.67	.83	.37	.84	.43	.84	.30	
LTP		.82	.99	.38		.55	.99	.20	
CMP			.81	.24			.55	-.04	
MPT				.41				.22	

* AGR refers to actual growth rate observed in the evaluation areas.

Table 8

Intercorrelation Matrices of SEDS Predictor and Criterion (AGR) Variables by Zone

made in the analysis. There is obvious regularity in the inter-correlations shown.* One can see that the predictors (STP, LTP, CMP, and MPT) are moderately correlated with each other, suggesting that each is not a source of unique information for making accurate predictions. Moreover, the overlap between LTP and MPT is almost total ($r = .99$), indicating that no loss of prediction accuracy would result if one or the other were dropped from the model. This result should not be totally unexpected given the knowledge that each of the temperature variables (LTMAT, STMAT) were calculated from one temperature (DMAT). Additionally, MPT was calculated directly from LTMAT and cannot, therefore, contain any information not contained in LTMAT (i.e., MPT is redundant).

The most disturbing finding from these correlation matrices, however, is the evidence on the predictor-criterion relationship. The growth rates of native populations, is denoted as AGR in Table 8. Clearly, no predictor variable shows even a moderate linear relationship with actual growth rate (AGR). This lack of relationship will effectively prohibit the SEDS model from making predictions of screwworm population growth rates with any acceptable degree of accuracy. At this stage of the analysis, a conclusion that the model suffers from rather severe deficiencies would not be unreasonable.

* The data illustrated here resulted from a sampling strategy of two days per week when weekly case reports equaled or exceeded ten. Inter-correlation based on other sampling strategies are quite similar.

When the SEDS multiplicative model was used to predict population growth rates in the field, the results were disappointing. Depending on the way in which county data was grouped (i.e., the various zone specifications), the sample multiple correlation coefficients were in the range .24 - .49 with many of these values between .35 and .49. Statistical tests on these coefficients concluded that most were not significantly different from zero (no correlation). The most optimistic interpretation of this data would conclude that, at best, only 25 percent of what contributes to screwworm population growth is represented in the SEDS model. Consequently, the remaining 75 percent of that variability is due to factors not measured by the SEDS system and not in the model. This unexplained variability will contribute to considerable error in any predictions of screwworm population growth made by the SEDS model.

Another problem with the model is the fixed time period for adult maturation. SEDS timing with a given screwworm generation is such that the population is four days old on the last satellite pass. The STMAT parameter is a running average of the temperature affecting these flies for the previous four days. By this time this population of flies is mating or has already done so. Considering that there is a required period of time for data processing, the data will arrive to the epidemiologist too late to be used on that population. Thus, the distribution of sterile flies based on the SEDS predictions would result in the release of flies in areas where the population has already mated (15).

Sexual maturation and preoviposition time are biological processes in insects that are temperature dependent. Therefore, it seems inappropriate to model an insect activity and have a set predictive time, especially when this setting is related to the most vital link in the whole eradication method: the placement of the sterile males in the field at the right time.

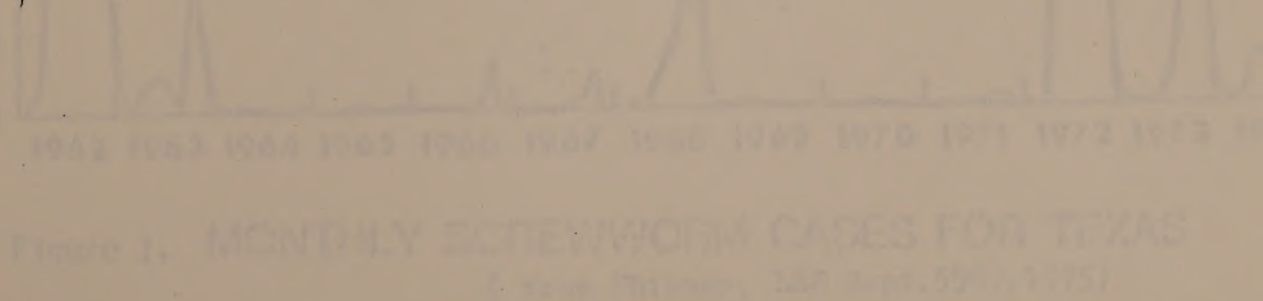
Two important biological properties of the screwworm populations make it extremely difficult to model, especially since little is known ecologically and behaviorally about the pest. First, very few insects of economic, medical or veterinary importance occur in such low densities yet cause such great damage. These low densities present special problems for the study of this insect. The low density problem magnifies the unreliability associated with the only population trend estimator, the case reporting system.

Second, in many seasons the screwworm in Texas may be considered as an invading population. With the warming temperatures in the spring and summer areas which were free of screwworm become suitable for the invasion and establishing of populations. Any model developed under these circumstances would be only applicable to areas with similar invading population characteristics, in which the effect of immigration of individuals is accounted for and taken into consideration. For example, Mexico has a continuous population of screwworms suggesting the need for model revisions to accomodate this fact.

The screwworm population model developed by Phinney (6) for the SEDS used case incidence data from Texas since the beginning of the eradication program. The data came from areas that are subjected each year to the release of sterile flies. However, the effect of the released sterile flies upon the natural population, as measured by the case incidence, has varied tremendously through the years. The case incidence has fluctuated from as low as 92 cases in 1970 to 8900 in 1973, to a maximum of 90,000 in 1972, which was considered a "non-normal" year. The 1975 infestation was 16,764 confirmed cases. Figure 7 (16) shows the monthly reported cases in Texas since the start of the eradication program.

Since the release of sterile flies in Texas is an ad hoc and not a preprogrammed operation, it has proved impossible to determine its effects on the screwworm populations of different areas.

The screwworm case reports sent in by the public and confirmed by APHIS are a very important part of the screwworm program and the SEDS model. Because of their importance, it is vital to have an understanding of their use and the inferences, if any, that can be drawn from them. The confirmed screwworm cases are qualitative values. They indicate the presence of screwworms but the values are not quantitative. The cases cannot be used as a direct indication of the total screwworm population or the number of cases actually occurring. There is considerable information in the case reports but it must be used carefully.



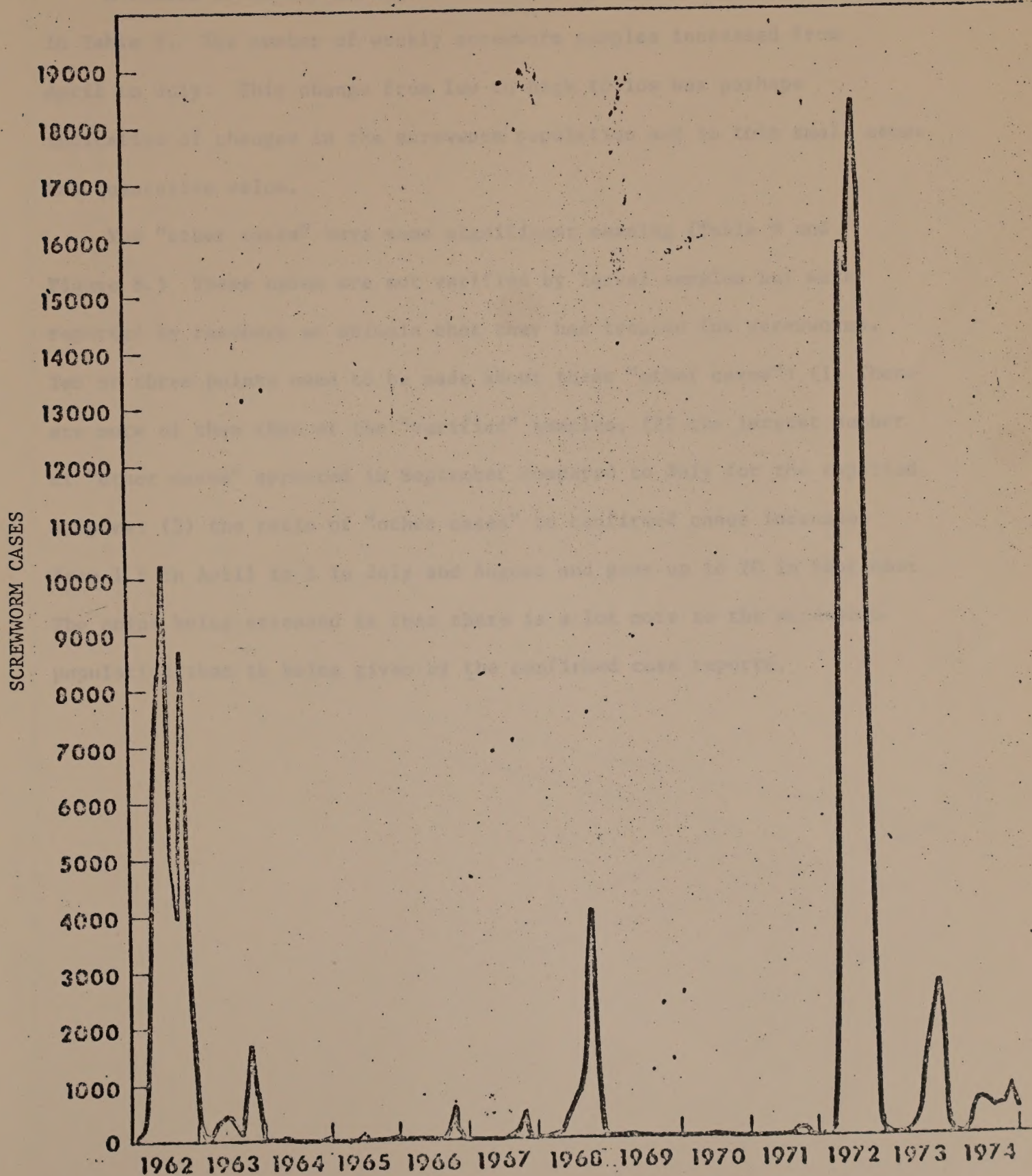


Figure 7. MONTHLY SCREWORM CASES FOR TEXAS
(from Phinney, IEC Rept. 5987, 1975)

A record of weekly screwworm cases from Kenedy County is found in Table 9. The number of weekly screwworm samples increased from April to July. This change from low to high to low was perhaps indicative of changes in the screwworm population and in this small sense has quantative value.

The "other cases" have some significant meaning (Table 9 and Figure 8.) These cases are not verified by larval samples but were reported by ranchers as animals that they had treated for screwworms. Two or three points need to be made about these "other cases": (1) There are more of them than of the "verified" samples, (2) the largest number of "other cases" appeared in September compared to July for the reported samples, (3) the ratio of "other cases" to confirmed cases increases from 1.5 in April to 3 in July and August and goes up to 20 in September. The point being stressed is that there is a lot more to the screwworm population than is being given by the confirmed case reports.

FIGURE 8
SCREWORM CASE REPORTS 1975: KENEDY COUNTY, TEXAS

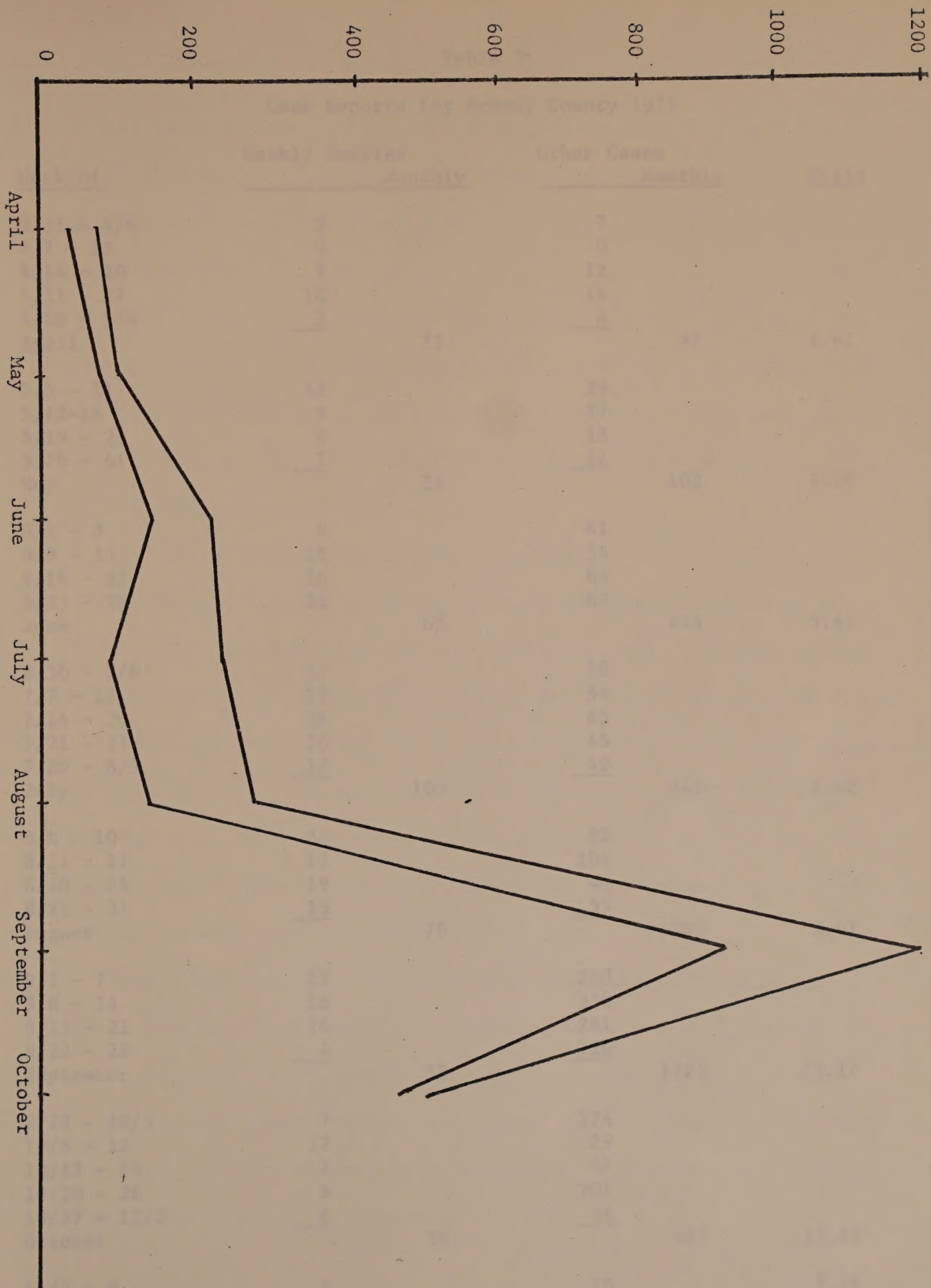


Table 9

Case Reports for Kenedy County 1975

<u>Week of</u>	<u>Weekly Samples</u> <u>Monthly</u>	<u>Other Cases</u> <u>Monthly</u>	<u>Ratio</u>
3/31 - 4/6	3	7	
4/7 - 13	0	0	
4/14 - 20	7	12	
4/21 - 27	10	14	
4/28 - 5/4	<u>3</u>	<u>4</u>	
April	23	37	1.61
5/5 - 11	12	39	
5/12-18	9	17	
5/19 - 25	6	15	
5/26 - 6/1	<u>7</u>	<u>31</u>	
May	34	102	3.00
6/2 - 8	9	41	
6/9 - 15	18	56	
6/16 - 22	16	65	
6/23 - 29	22	62	
June	65	224	3.45
6/30 - 7/6	17	38	
7/7 - 13	22	54	
7/14 - 20	24	65	
7/21 - 27	20	45	
7/28 - 8/3	<u>17</u>	<u>40</u>	
July	100	242	2.42
8/4 - 10	24	82	
8/11 - 17	17	104	
8/18 - 24	19	44	
8/25 - 31	<u>19</u>	<u>55</u>	
August	79	285	3.61
9/1 - 7	17	260	
9/8 - 14	16	358	
9/15 - 21	16	281	
9/22 - 28	<u>4</u>	<u>326</u>	
September	53	1225	23.11
9/29 - 10/5	7	174	
10/6 - 12	12	29	
10/13 - 19	7	47	
10/20 - 26	6	201	
10/27 - 11/2	<u>6</u>	<u>36</u>	
October	38	487	12.82
11/3 - 9	9	70	7.78
Total	401	2676	6.66

It is of interest to follow the identified nonscrewworm cases. APHIS's records indicate that they remain quite constant throughout the year. Implications from this is that the increase in "other cases" is mostly screwworm.

It appears to be an accepted philosophy that when the screwworm cases get bad the proportion reported drops off. This is suggested in the ratio of "other cases" to "verified cases" during the summer and fall months. Many ranchers have admitted that they do not report every case and some ranchers do not send in any.

Another problem in using verified screwworm cases as quantitative information to estimate growth is the date of sample identification. Table 10 contains data showing relationships between the reporting or identification date to sample collecting date. Although only two dates in October are shown, these results are very typical. The cases identified and reported on a given date were actually collected some 5 to 15 days earlier. This little problem was corrected for some of the final evaluations of SEDS but the growth potential relationships were developed using the case identification date.

Very simple examples have been used to discuss and evaluate the date of reporting and "verified cases" vs. "other cases;" however, the evidence is sufficient to make the point that verified case reports are at best qualitative estimators and not quantitative. Any relationship which purports to estimate quantitative information from undadjusted verified case reports is unsound.

Table 10
CONFIRMED (IDENTIFIED) SCREWORM SAMPLES AND "OTHER" SAMPLES

Date Sample Identified	Total	October										Date of Collecting										Earlier than 10/7	Non Screwworm
		25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10						
10/21/75																							
No. Samples	168						30	51	54	18	3	3	1	1	2	1	3	7	2				
No. Other Cases	223						16	54	109	6	0	10	15	0	8	0	0						
10/27/75																							
No. Samples	103	1	19	38	21	8	6	2		2	1	1							1				
No. Other Cases	304	0	7	259	23	3	3	3		6	0	0											

Furthermore, the model uses verified larvae as a quantitative estimate of screwworm presence. This fails to recognize that larvae and adults exist in completely different environments which may or may not be independent from one another. When a case is confirmed there is no way of knowing if the case is due to a migrant fly, an infested animal who was relocated an extensive distance from the initial infestation, or due to a fly existing in that immediate environment. Additionally, it must be recalled that a positive sample indicates only that a case existed in that area. The converse may or may not be true, i.e. no sample submissions from a given area do not necessarily indicate there are no cases, only that none has been submitted.

The presence or absence of suitable hosts and the incidence of wounds has long been accepted as the major component in the life cycle of screwworms and, in fact, is used as a major method for controlling screwworm populations. The importance of the presence of wounds can be exemplified by the years of 1973 and 1975 which would have had a low screwworm incidence had it not been for the outbreak of the Gulf Coast Ear Tick (*Amblyomma maculatum*) which created an abundance of ovipositional sites. Even in bad years, such as 1972, Bruce (17) reports that ranchers who were able to control and limit wounds were not seriously affected by screwworms. Lindquist (18) has shown that the presence of wildlife and their activities (such as fawning) affect screwworm populations.

The physiological state of the wound apparently affects the attractiveness of the wounds to gravid screwworm females. For example, new-born calf navels are highly susceptible to infestation, while dehorning wounds are less so. An infested wound is more highly attractive to screwworm females than one which is uninfested. The point is that there can be no screwworms where there are no wounds; there can be no wounds where there are no animals. Additionally, wounds are not identical, some wound types are at a higher risk than others. Unfortunately, only limited information is available concerning livestock, wildlife, and the number of each which are a risk at any given time. The present model of SEDS has completely ignored these factors. There is little doubt that they are extremely important in screwworm population dynamics; furthermore, it is not unreasonable to assume that this set of factors alone would determine the success or failure of the SEDS to predict screwworm populations.

D. Technology Transfer; Costs and Benefits

The principal charter of the Benefit-Cost subgroup was to conduct a benefit-cost analysis of SEDS if it was an operational system. The analysis was to be based on the findings of the Product Evaluation subgroup coupled with findings of the Benefit-Cost subgroup in the areas of automation and technology transfer.

In approaching the project the subgroup was aware of the following facts:

1. The sterile screwworm fly technique of eradicating and controlling screwworm has been tested and proven effective. The United States has been freed of self-sustaining screwworm fly population.

2. At present screwworm migration into the United States is controlled by maintaining a sterile fly barrier. The barrier is a designated area presently extending along the Mexico-United States border from the Gulf of Mexico to the Pacific Ocean. Periodically conditions become extremely favorable for the propagation of screwworms and massive outbreaks occur in the United States (1972).

3. The number of flies dropped in the barrier varies according to seasons of the year; climatic conditions during the year; and field survey reports on the numbers and locations of native fly populations especially in northern Mexico. High concentrations of sterile flies are released in areas where outbreaks have occurred, along river courses, and other areas where conditions are favorable for the propagation of native screwworms.

4. During FY 1976 the annual costs of maintaining the present barrier along the U.S. border and losses to the U.S and Mexico are expected to reach \$51.2 million. Inflation and increased numbers of screwworm outbreaks over the past several years have greatly affected the cost of the screwworm program. The total cost of maintaining the U.S. barrier in FY 1974 was \$11.7 million, \$13.4 million in FY 1975, and is expected to cost \$14.0 million in FY 1976.

5. In FY 1973 Congress approved and appropriated funds to begin a U.S.-Mexico Screwworm Program with the objectives of eradicating screwworms from Mexico and establishing a barrier at the Isthmus of Tehuantepec in southern Mexico. A study carried out by the U.S. Department of Agriculture and the Ministry of Agriculture and Livestock of Mexico in 1966 indicated that such a program was feasible.

6. In 1973 a suitable site for the plant was located and in 1975 a clear title to the land was obtained. Construction of the plant has begun and is expected to be completed and in full production in FY 1977. It is expected that eradication of screwworms can be completed by 1982. The cost to eradicate screwworms in Mexico is projected to be about \$129.3 million. Once screwworms are eradicated, the cost to maintain the new barrier is expected to be about \$2.7 million. About \$476,000 will be needed to eradicate spot outbreaks that occur once the barrier is established.

7. Projected annual costs plus losses to the U.S. and Mexico can be reduced from \$54.5 million to \$3.4 million by the year 1982 with a Joint U.S.-Mexico Screwworm Program. For the period covering from 1973-1981, the total cost of the program would be \$232.9 million--\$104.6 million above costs to continue the present U.S. Barrier Program.

8. The cost of maintaining the new barrier and eradicating spot outbreaks of screwworms would be about \$3.2 million--\$12.4 million below the expected annual cost of the U.S. Barrier.

9. The breakeven point of the new program is projected to occur in 1981 when the cumulative costs plus losses to the U.S. and Mexico would fall below the projected costs plus losses expected in the U.S. and Mexico if the U.S. Barrier program is continued. (See Figure 9, and Table 11.) The benefit-cost ratio of a U.S.-Mexico Eradication Program versus the U.S. Barrier Program is 3.01 using a 10 percent discount rate.

10. A program to eradicate screwworm in Mexico would lead to a sharp reduction in costs and losses under the U.S. Barrier program--about \$236 million by the end of 1985. Since the program has been tested and proven, there is a high probability that eradication can be achieved in the given time frame providing that full production of flies can be accomplished by FY 1977.

Fig. 9 Cumulative costs plus losses to U.S. and Mexico for U.S. Barrier (Line A) and U.S.-Mexico Program (Line B).

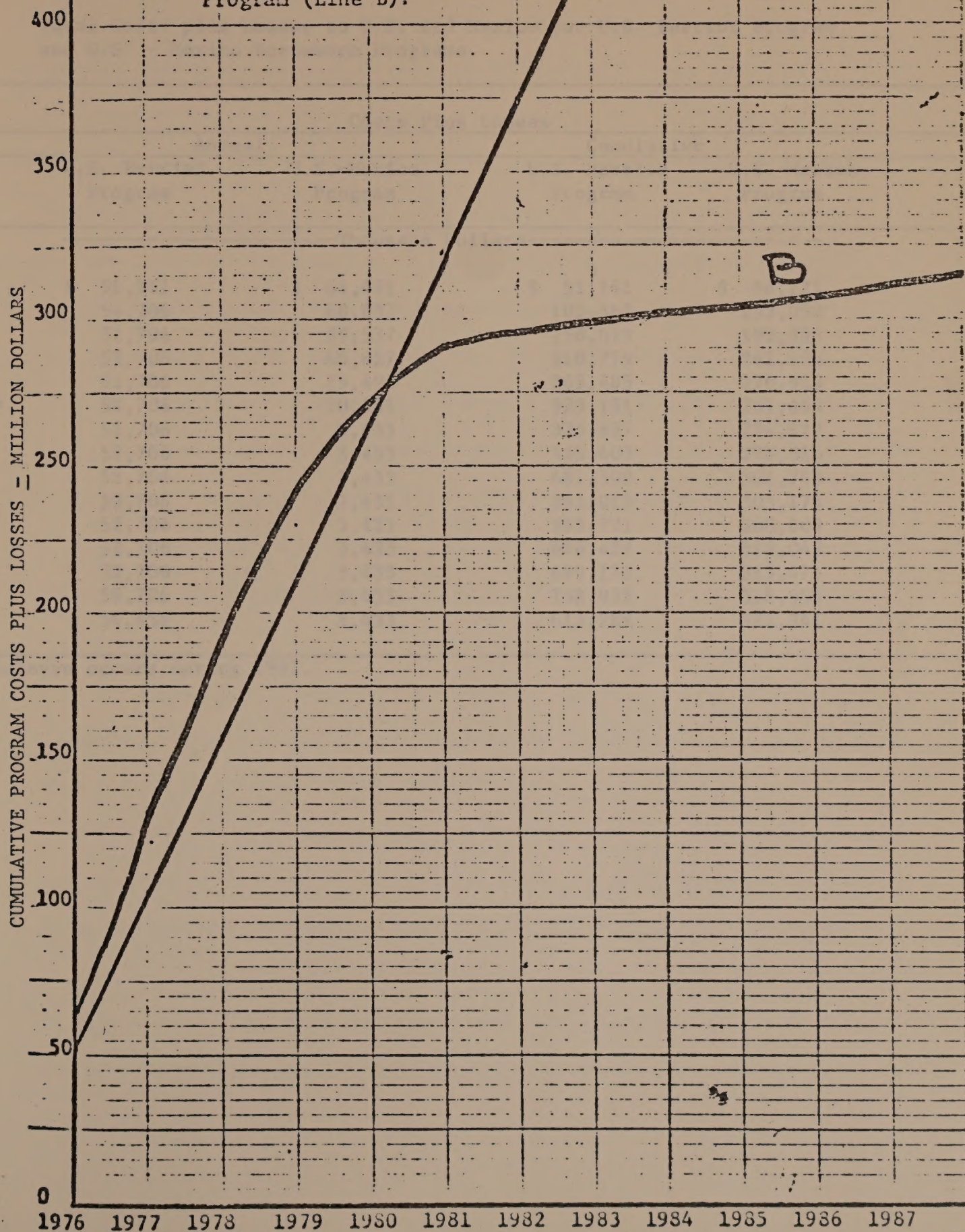


Table 11

Total Costs plus Losses to U.S. and Mexico for U.S. Barrier Program
and U.S. - Mexico Screwworm Programs.

Year	Costs Plus Losses			
	Annual		Cumulative	
	U.S. Barrier Program	U.S.-Mexico Program	U.S. Barrier Program	U.S.-Mexico Program
-----Thousand Dollars-----				
1976	\$ 51,161	\$ 64,421	\$ 51,161	\$ 64,121
1977	54,206	68,637	105,367	133,058
1978	52,706	59,537	158,073	192,595
1979	52,706	48,827	210,779	241,422
1980	52,706	29,491	263,485	270,913
1981*	59,706	20,531	323,191	291,444
1982	52,706	3,433	375,897	294,877
1983	52,706	3,433	428,603	298,310
1984	52,706	3,433	481,309	301,743
1985	59,706	3,433	541,015	305,176
1986	52,706	3,433	593,721	308,609
1987	52,706	3,433	646,427	312,042
1988	52,706	3,433	699,133	315,475
1989	59,706	3,433	758,833	318,908
1990	54,456	3,433	813,289	322,341

* Breakeven occurs during 1981.

11. The Lincoln-Eden Report (19) issued in 1974 stated in part "there is no question in our minds but that the Screwworm Program has resulted in tremendous returns to the nation." This conclusion was based in part on the findings of a study by Dr. Tom Prater, Agricultural Economist, Texas A&M University and Dr. John Goodwin, Oklahoma State Department of Agriculture which showed a 1:113 cost-benefit ratio for the Screwworm Program for FY 1973. Another study conducted by Dr. Edward Uvacek, Jr., Livestock Marketing Specialist at Texas A&M at the request of Drs. Lincoln and Eden showed a cost-benefit ratio of 1:39. The lower ratio reflected a more elastic demand curve for beef, yielding a closer relationship between consumption change and price change than presented in the Prater-Goodwin study.

The preceding facts clearly indicate that the current system for eradicating and controlling screwworm has been both successful and cost effective.

The main purpose therefore of considering SEDS was to determine if the time frame for carrying out the program could be significantly reduced, thus resulting in even greater savings.

The benefit-cost analysis was to be conducted if SEDS was operational applying the definition of operational found in Appendix 14 of the Requirements Implementation Analysis Instructions (20) which were developed for use by the USDA Remote Sensing User Requirements Task Force, chartered in August 1973. The USDA members of the SEDS Joint Evaluation Team concluded that SEDS was not operational. Operational is defined as follows:

"Technology is well established, known, used or understood by at least a cadre of USDA employees. This familiarity with new technology is acquired through trial use and evaluation or operational simulations conducted in developmental phases. For operational status commercial capability exists to collect new data, required hardware and communication facilities are in place or available, and software is developed and available for routine use."

During the preliminary factfinding stages, several observations were made. Due to the significance and relevance of this information, it has been incorporated in this section of the report.

SEDS produces information. The value of this information is dependent upon the planner's ability to interpret the color-coded maps or a numerical estimate. It then becomes a decision tool which, if rightly interpreted and collated with other biologic information, such as case reports and operational delivery capabilities, could produce a return to the program and to the livestock industry. If the SEDS information is not reliable or is misinterpreted, losses can result from wasted flies or by allowing unidentified populations to flourish.

The output of the SEDS is a color-coded series of computer-produced map images of Mexico and the southwestern United States. The maps are reproduced by use of a photographic process. The key product is a map which combines temperature, soil moisture and degree day accounting. This is correlated to tolerances of the screwworm fly in its life cycle phases to these combined weather factors. Areas on the map coded in red identify those geographic places which have experienced a period of weather highly favorable to the proliferation of screwworm flies. Several problems identified are:

1. Those areas known to be free of the pest, are not eliminated.

2. Biologic considerations such as presence of host animals and availability of wounds are not incorporated into the model.

3. The accuracy of the weather information is periodically distorted by cloud cover at the time of the satellite pass.

4. The temperatures are those at the time of observation. This could miss the potentially lethal high and low temperatures of the day.

It is difficult with present SEDS data to document a favorable cost-benefit ratio because the programs involved are still in a research and development stage. There is no evidence that the perceived benefits of SEDS will be realized.

The principal benefits of SEDS as a concept are:

1. Increased geographic coverage.
2. Detail.
3. Reliability.
4. Frequency.
5. Information acquisition otherwise unobtainable in Mexico.

The hope was that SEDS information alone could shorten the time required to eradicate the screwworm fly from Mexico to the new barrier. Early completion of this task would indeed be cost-effective but was dependent upon an operating SEDS. A secondary multiplier effect would be savings resulting from prevention of livestock losses and labor cost for infested animal handling and treatment.

There is no firm evidence that SEDS will enable a shorter eradication plan. The arguments that a savings will result are subjective and judgemental.

If funding for SEDS were made available from APHIS, it should be treated as an additional cost to the Program.

Assuming that APHIS would wish to continue operation of SEDS, the lowest cost method to accomplish this is by use of outside services. Aeroneutronic Ford, one of the current SEDS contractors, submitted an unsolicited bid to perform SEDS processing including personnel and equipment for \$390,000 per year. This estimate was based upon the products, support services and processing intervals currently performed by NASA. It should be noted that the current NASA processing has a lag time of eight days caused by tapes mailed from either the East or West coasts. This lag time is operationally unacceptable for fly drop planning. The delay could be eliminated by acquisition and installation of an antenna to receive the data from the satellite in Houston. In order to make the processing timely, an estimated additional investment of \$350,000 for purchase of an antenna would be needed. This would be a one-time start-up cost. The vendor estimate is in line with NASA budgets for this project. The NASA budgets were as follows:

1972	--	\$224,000
1973	--	\$257,000
1974	--	\$201,000
1975	--	\$271,000
1976	--	\$315,000

As an alternative to vendor supplied service, the cost for APHIS to assume in-house operational responsibility were estimated in Table 12.

TABLE 12

ESTIMATED COSTS OF USDA OPERATION OF SEDS

IN-HOUSE OPERATION

	<u>First Year</u>		<u>Second Year</u>	
	<u>Own Staff and Equipment</u>	<u>Antenna at Houston</u>	<u>Own Staff and Equipment</u>	<u>Antenna at Houston</u>
Personnel - 15 People	\$ 470,000	\$ 470,000	\$470,000	\$470,000
Equipment	847,000	847,000		
Delivery Service	4,000		4,000	
NOAA Tape Handling	10,763		10,763	
Maintenance	30,000	30,000	30,000	30,000
Own Antenna		350,000		
Data Delivery to Mexico	5,200	5,200	5,200	5,200
Total	\$1,366,963	\$1,702,200	\$519,963	\$505,200

A big factor in this estimate is the cost of a Production Film Converter (PFC). This item costs \$550,000. This is the cost of equipment currently used to process SEDS film. Almost everyone associated with this project agrees that lower cost equipment could be used. The APHIS evaluators felt that a computer printout with actual numerical values in lieu of the photo map representation would be a better planning tool. Under this method of processing, the photo processing could be eliminated from the system. Tentative evaluations indicate that equipment in the \$80,000 range could be used to process the photos if photos are deemed necessary.

The \$390,000 vendor offer is the greatest value. The vendor has both the experienced staff and equipment to process the work. The vendor can achieve economies because the staff and equipment are shared with other revenue-producing contracts. Although the prospect of a better price could be obtained from competitive bids, this was not investigated.

The high cost of an in-house operation rule this approach out as a cost-effective alternative. The technical risks associated with an in-house start-up for SEDS are high. The technical documentation for SEDS is possibly sufficient for experienced personnel who have operated the system from inception. The vendor personnel have broad experience in programming and processing aerospace applications. A long learning period would be needed to bring an outside team to proficiency.

It appears that the only SEDS variable of potential value is temperature. Considering the importance of the many other variables that impact on the screwworm life cycle which have been discussed earlier in this text, it is questionable if a significant financial investment in a system that predicts only temperature will be prudent. Particularly since the system provides only daily averages and does not reflect soil temperatures, but temperatures read at 5 feet above the soil surface.

With regard to documentation available for technology transfer, the document entitled "System Development of the Screwworm Eradication Data System (SEDS) Algorithm" (24), was provided by NASA. This documentation is inadequate for operational transfer of the SEDS system. The requirement for a more thorough document is evidenced by the following observations:

1. It cannot be assumed that those responsible for implementing the system will have access to the several references cited in the document. These references are available at NASA and copies should become part of the total transfer package.

2. There is need for a total system overview chart illustrating the complexity and interrelationships among the several subsystems in an input-processing-output general format. For example, when and how does the SEDS system access the LARSYS classifier programs.

3. There is need for a general flow chart of the application and utility programs used to process the system. A narrative description of the functions performed by each program is necessary.

4. Equipment resource utilization is needed for any technology transfer for operational scheduling and transfer. For transfer of the SEDS system, we would require documentation of core space, duration of runs, tape and disc units and file sizes involved in processing.

5. Computer program listings should be bound with representative output listings, error messages and other characteristic diagnostics associated with processing. The bound program listings should be identified with the same titles shown in the general flow chart.

6. There are instances within the current document where formulae are incomplete or poorly explained. All such expositions should be reviewed for completeness as a stand-alone item. A few examples of this problem are:

- a. (Pp. 2-19) What is denoted by the symbol $\frac{v^2}{4}$ on line 9?

b. (Pp 2-19) Where does the symbol S^2 come from; its use is not defined in the text.

c. (Pp 2-22) In Table 2-VIII, a column entitled "Correlation Coefficients" does not contain correlation coefficients. What do the entries represent?

d. (Pp 2-42) Line 6 contains the variable DDSYN. Is this the appropriate name or a typo (i.e., should be DDSUM)?

7. Appendix A entitled "Operation of E-Disk Program". What is the E-Disk program and where does it fit within the system?

The deficiencies noted above do not necessarily constitute a new workload requirement. From observations made at NASA, it is believed that the required documentation is available. The task is one of careful review, organization and compilation of existing documents into a complete transfer package.

It is conceivable that the ultimate goal of SEDS would be to predict population growth on a seasonal basis for Mexico. The eventual use of such a prediction would allow production and release to be geared for population trends, Jim Webber (23). This envisioned use is a conceptual outline of such a predictor. As stated in the text, the outline is based on multiple inputs which include sterile fly ratios based on Knipling's models (21), historical data, rancher cooperation and weather data input (SEDS).

It would be extremely difficult to integrate this into an operational program for the following reasons:

1. Dr. Knipling, when developing his model, used a 10 to 1 ratio of sterile to wild flies based on caged studies. Therefore, the results do not relate to wild populations.

2. Although many years will be required to develop the historical data for any given area in Mexico, information is presently being accumulated. The only historical data presently available is contained in the Sherman Report (1966). This data may or may not be accurate in terms of population trends.

3. Detailed information will probably be difficult to gather. It is unlikely that the ranchers in Mexico will be able to collaborate with the Screwworm Program officials to an extent greater than their U.S. counterparts.

REFERENCE MATERIAL

1. Jim Boatright, AFC/NASA, Personal communications with H. D. Peterson, February 10, 1976, College Station, Texas.
2. Dale Phinney, LEC/NASA, Personal communications with H. D. Peterson and K. G. Wissmann, January 21, 1976, NASA, Houston, Texas.
3. Dale Phinney, LEC/NASA, Document 2.2.1., Houston, Texas
4. S. Boatright, AFC/NASA, Letter to R. Spaulding, October 16, 1975, "SEDS Registration Accuracy Study," Document 3K2340, Houston, Texas.
5. G. Arp, LEC/NASA, Presentation to JET, January 22, 1976, NASA, Houston, Texas.
6. Dale Phinney, LEC/NASA, Document 2.1.3., 92-105, Houston, Texas.
7. Dale Phinney, LEC/NASA, "Rough Draft Presentation of Evaluation of DMAT Estimates," Houston, Texas.
8. Dr. Elwin Taylor, National Weather Service, Auburn, Alabama, Personal communications with H. D. Peterson, January 21, 1976.
9. Flitters, N. E., and Benschoter, C. A., "Survival of Screwworm Pupae Exposed to Simulated Winter Temperatures from Selected Sites in Texas." Ann. Entomol. Soc. Amer. 61: 65-67, 1968.
10. Rahn and Barger, "Weather Conditions and Screwworm Activities." Agricultural Meteorology II: 197-211, 1973.
11. Palmer, W. C., "Keeping Track of Crop Moisture Conditions Nationwide: The New Crop Moisture Index." Weatherwise, 156-161, August 1968.
12. Baumhover, A. H., "Susceptibility of Screwworm Larvae and Prepupae to Desiccation." Journal of Econ. Entomol. Vol. 54: 4, 473-475, 1963.
13. Chris Hofman, USDA Screwworm Eradication Facility, Mission, Texas, Personal research (1976, unpublished)
14. Dale Phinney, LEC/NASA, Document 4266, September 1974, Houston, Texas.
15. Alberto Broce, LEC/NASA, "Subjective Analysis of SEDS," January 16, 1976, Houston, Texas.
16. Dale Phinney, LEC/NASA, Document 5987, April 1975, Houston, Texas

17. J. J. Bruce, USDA, APHIS, personal communication with C. Hofman, December 1975.
18. Lindquist, A., "The Use of Gamma Radiation for Control of Eradication of the Screwworm," The Journal of Economic Entomology, 48: 467-469, 1955.
19. Eden, W., and Lincoln, C., "The Effectiveness of the Screwworm Control Program." Report to Subcommittee on Agriculture-Environmental and Consumer Protection, U. S. House, October 17, 1974.
20. Report of USDA Remote Sensing User Requirements Task Force, August 1975, Appendix 14.
21. Knipling, E. F., "Screwworm Eradication: Concepts and Research Leading to the Sterile Male Method." Annual Report Smithsonian Institution, pp 409-418, 1958.
22. Sherman, "Report of Findings of the Mexico-United States Screwworm Survey and Plan of Operation for a Possible Eradication Program in Mexico," 1966.
23. Jim Webber, LEC/NASA, Screwworm Eradication Data System (SEDS) Operational Implementation Concept. Working paper, 1975.
24. System Development of the Screwworm Eradication Data System (SEDS) Algorithm, LEC/NASA, January 1976, Houston, Texas.

